PRACTICAL ENERGY AUDIT MANUAL

Compressed Air Systems

Prepared by

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for

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PREFACE

Energy inputs - both electrical and fuel - are an essential part of manufacturing process, and expenditure on these inputs often accounts for a significant share of the manufacturing cost. This is compounded by the fact that the cost of energy is constantly escalating and will continue to rise.

Any saving in energy costs directly adds to the operating profits of the company. It probably requires less effort to improve profits through energy savings than by - reducing labour cost, increasing sales, increasing prices, reducing distribution costs, etc.

The main purpose of an energy audit is to systematically identify practical and feasible opportunities for saving all forms of energy in a plant and realise the benefit of cost reduction. Experience shows that as much as 10-15 percent of energy could be saved without any need of large investments, through energy audits.

The main objective of this manual is to familiarise the plant personnel in the techniques, methodology and approach to in-house energy audits. Since energy conservation is essentially a continuous exercise, it is inevitable that the plant personnel are able to regularly monitor trends in energy consumption and initiate remedial measures to improve energy efficiency.

Section 1 - Introduction

The term energy conservation itself seems sometimes to be an anomaly, in the context of the tremendous emphasis being laid on increase of production, efficiency, productivity - How can all this work be done, without increasing energy? And if energy consumption is increased, is conservation so much idle talk? No! - not any more. Conservation, now a buzzword in the industry, is the process of increasing productivity by actually consuming less energy - through more efficient practices and making best use of the high-technology that is creeping in faster and faster everyday, into all spheres of industrial activity.

Energy management is a concept, devised by the new generation of industry protégés for the efficient use of energy without compromising upon production levels, product quality, safety and environmental standards. The core philosophy of this concept is, of course, the cost effectiveness – conservation cannot be conceived without justification in commercial spheres.

Financial and technical evaluations of every recommendation to conserve energy are inevitable, nay mandatory, to ensure that the bottom line is not straggling at the expense of a lower energy consumption. One other factor to be considered is the general malaise gripping the industry in terms of a resistance to change - which very often requires education and awareness to overcome the hurdles of implementation of novel ideas.

Specific energy consumption – the amount of energy consumed per unit of output – varies widely depending on the product in question, type of process, type of fuel consumed, age of equipment, operating practices and, even to a certain extent, the management philosophy.

Compressed air systems are among the most common industrial electrical equipment and in industries such as the automotive, tyres and glass sectors, can account for almost 50 to 60 percent of the total electrical energy consumption.

Experience shows that energy savings are significant and long lasting, when they are achieved as part of a plant energy management programme. A systematic and structured approach is required to identify and realise the full potential of savings that can be achieved, mainly through low-cost measures. The energy management programme can be made "self-financing" - with the savings of the low-cost short term measures being utilised for the implementation of more capital-intensive retrofits. **The core of such a programme has to be a**

comprehensive and professional energy audit, in order to assess the current consumption pattern and identify potential opportunities, given the existing framework and infrastructure of the industry. However, the savings for a plant, just embarking upon an energy management programme, are often 20 to 30 percent of current consumption patterns. To quote a very relevant instance:

Annual energy cost for a reciprocating compressor in a processing industry at current costs	: Rs. 2 million
Assuming a baseline conservation of 5 percent	: Rs. 0.1 million

...ery good business sense !

Compressed air is used mainly for pneumatic applications and instrumentation systems. It is one of the most expensive of all services to be provided, an irony considering the fact that air is available free of cost to all !

Why so? The reason is simple - An analysis of the energy breakdown of a compressed air system, through the construction of a detailed energy balance, shows that as little as 10 percent of the input power supplied to the compressor is delivered as compressed air to the system. Almost 80 percent of the input power is rejected as heat from the compressor.

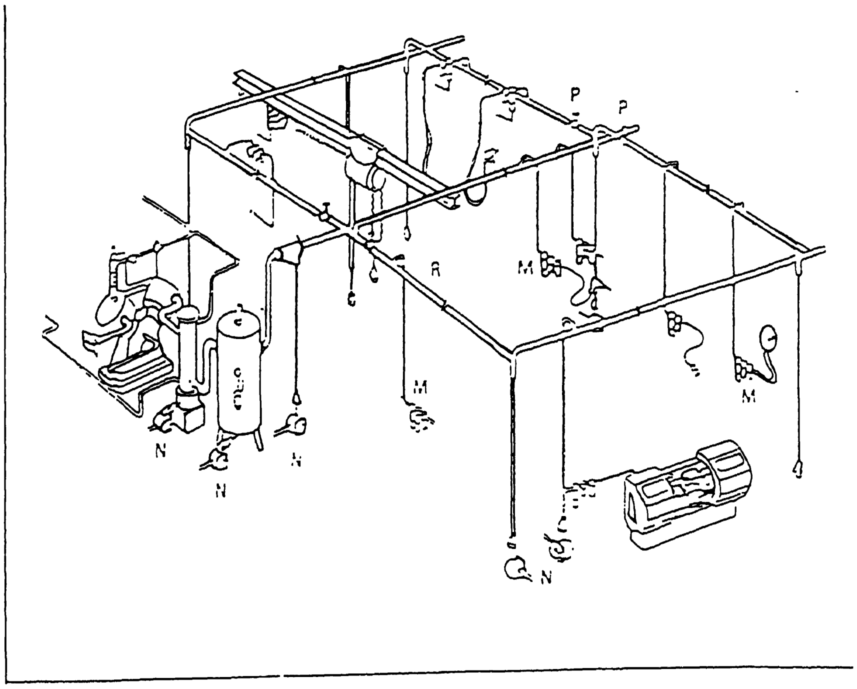
But, with this knowledge itself comes the solution to conservation. The ideal solution is to minimise the 80 percent rejection in order to improve the efficiency of the compressor.

1.1 Basic Components of a Compressed Air System

The compressed air system normally consists of various subsystems and equipment such as:

- Air compressor with air filters, inter coolers, after coolers, dryers, oil and moisture separators
- Lubrication and cooling water system
- Air receivers with safety valve, pressure gauge and drain valve
- Motor and drive transmissions
- Distribution system comprising piping, valves, non-return valves, pressure regulators, lubricators, flow meters, couplings and bends
- End use equipment such as pneumatic drills, presses and spray guns.

Fig. 1.1 : Typical Compressed Air System Installation



M - Appropriate Air Service Unit
P - Isolating Ball Valve
N - Drain Trap
R - Correctly Sized And Installed Pipe

A typical compressed air system is shown in Fig. 1.1

2.1

2.2

Section 2 - Types of Compressors

This chapter briefly discusses the various types of industrial compressors generally in use. As in all other spheres, there has been a significant leap in technology, which has not only improved operation, but also the environment and quality of output.

Reciprocating Compressors

Reciprocating compressors are widely used, are available in a range of different models, depending upon the capacity and pressure ratings. They are highly efficient and have the additional advantage of control systems to match output to operational demands. The smaller compressors are air-cooled, while the larger capacity ones are water-cooled. Reciprocating compressors are available in either single stage or multi stage. The number of stages is determined by the required compression ratio. Generally the maximum allowable discharge gas temperature determines the compression ratio.

Single-acting air-cooled and water-cooled compressors are available in size upto 75kW. These compressors are rarely used for gas compression because of the difficulty in preventing gas leakage and contamination of the lubricating oil. However, the compressors most commonly used for compressing gases have a cross-head to which the connecting rod and piston rod are connected. This provides for a straight line motion of the piston rod and allows for simple, effective packing; hence reducing the likely hood of gas leakage.

In multi-stage compressors, the heat generated is removed through inter-coolers. These inter-coolers are designed in such a manner that the gas temperature at out let is as near to the gas temperature at the inlet of the compressor stage.

Rotary Vane Compressors

These are small in size and have a pulsation free output. They have a rotor, with free blades to slide in radial slots, rotating off centre in a cylindrical chamber. The rotation causes the blades to be thrown out by a centrifugal force, and sweep the compression chamber. In order to seal the chamber and lubricate the blades, a small amount of oil is admitted into the chamber, which also acts as an internal coolant. Rotary vane compressors are generally constant volume machines with variable discharge pressures. The volume can be varied only by changing the speed of the machine or by bypassing or even wasting some of the capacity of the machine.

Rotary vane compressors come in various types such as straight–lobe type, sliding vane type and liquid piston type.

2.3 Screw Compressors

These are high-speed, high-capacity machines. Relatively small diameter rotors allow rotational speeds of several thousand rpm. These machines are provided with intercoolers when such arrangements are required. Their high speed operation requires the use of suction and discharge noise-suppressers. They are available in both the dry and oil injected types, with single or twin screws mounted horizontally or vertically. The dry type deliver air up to a pressure of 15 bar, while the lubricated type can deliver air only between 3.5 bar and 10 bar. Another requirement is that the oil has to be separated from the discharged air.

2.4 Centrifugal and Axial Compressors

These develop air pressure by the action of rotating blades, which impart velocity and pressure to the flow medium. They are suitable for high gas volume applications such as chemical industries such as nitric acid plants, in steel plants where centrifugal compressors are used in blast furnaces, oil refineries and gas transport systems. In most cases the design of the rotary compressor has to ensure that there isn't any oil contamination in the output-compressed gas. They are inexpensive and are available in compact sizes for large capacity requirements. They are typically mullet-stage machines, suitable for high compression ratios. The principal of operation of the centrifugal compressor is the same as that of the centrifugal pump. The only difference being that medium is a compressible gas in the case of a centrifugal compressor, where as the medium is more or less incompressible in the case of a centrifugal pump.

The selection of a centrifugal compressor depends on certain conditions:

- Lowest intake pressure
- Maximum inlet gas temperature
- Highest ratio of Cp/Cv
- Lowest barometric pressure
- Lowest specific gravity
- Maximum intake volume
- Maximum discharge pressure

In the chemical Industry, most centrifugal compressors are either driven by steam, gas turbines or electric motors. In some cases, it may be necessary to

attach speed-increasing gearboxes. Since the rotational speeds are very high, the material of construction of the blade becomes a limiting factor. Speeds of up to 50,000 rpm are not uncommon in gas compression applications. There is a minimum capacity for each stage, below which the operation becomes unstable. The instability may be accompanied by noise and hammering sounds, indicating the stress to which the rotor is subjected. The compressor should not be operated below this minimum capacity. In keeping with the dynamics of rotor motion, a single casing does not contain more than seven or eight stages of compression.

The rotary compressor can be controlled either by speed variation or by altering the angle of the guide vanes. The guide vanes can be adjusted to vary the capacity of the compressor. For instance by reducing the capacity of the compressor, under plant requirements, the machine can be run at stable conditions. It may be worthwhile mentioning that the use of a blast-gate in the suction pipe is not an efficient practice and variable guide vanes are the most energy efficient. By proper selection of the method of control, the performance of the centrifugal compressor can be optimised.

Section 3 - Opportunities for Energy Conservation

In discussing the opportunities to conserve energy in a compressed air system, the individual opportunities have been classified, as per the return on the investment in terms of simple payback period, as short term, medium term and long term or technological changes. The need for conservation is itself evident from the table below.

Table 3.1 : Actions to Improve Compressed Air Systems and Likely Savings

Action	Likely Savings (%)
Leak Repair	9 - 15
Compressor Control	5
Downsizing of Compressor	4
Other Measures such as outdoor air intake, reducing air pressure, air flows, etc.	3

3.1 Use blowers instead of compressors for low pressure loads

Short Term

Since the compressed air system is already available, facilities engineers may be tempted to use compressed air to provide air for low pressure requirements such as agitating plating tanks or pneumatic conveying. Using a blower that is designed for lower pressure operation will save substantially on the cost of providing air to the process. The practical aspect has been discussed in a relevant case study.

3.2 Location of Compressors

Short Term

Location of air compressors and the quality of air drawn by the compressors can also have a significant bearing on the amount of energy consumed. Compressor performance can be affected by cool air, clean air dry air and pre-cooled air.

Cool air intake

Every 4°C rise in inlet air temperature results in a higher energy consumption by 1% to achieve equivalent output. Hence, cool air intake leads to a more efficient compression.

Table 3.2 : Effect of Intake Air Temperature on Power Consumption

Inlet Temp (°C)	Relative Air Delivery (%)	Power Saved (%)
10.0	102.0	+ 1.4
15.5	100.0	nil
21.1	98.1	- 1.3
26.6	96.3	- 2.5
32.2	94.5	- 4.0
37.7	92.8	- 5.0
43.3	91.2	- 5.8

It is preferable to draw cold ambient air, as the temperature of air inside the compressor room will be a few degrees higher than the ambient temperature. A sheltered inlet protected from rain on a north wall is desirable. While extending air intake to the outside of building, care should be taken to minimise excess pressure drop in the suction line, by selecting a bigger diameter duct with minimum number of bends.

Dust free air intake

Dust in the suction air causes excessive wear of moving parts and results in malfunctioning of the valves due to abrasion. Suitable air filters should be provided at the suction side. Air filters should have high dust separation capacity, low pressure drops and robust design to avoid frequent cleaning and replacement.

Table 3.3 : Effect of Pressure Drop across Air Inlet Filter on Power Consumption

Pressure drop across air filter (mm wc)	Increase in power consumption (%)
0	0
200	1.6
400	3.2
600	4.7
800	7.0

Air filters should be selected based on the compressor type and installed as close to the compressor as possible. For every 25-mbar pressure lost at the inlet due to choked filters, the compressor performance is reduced by about 2

percent. Hence, it is advisable to clean inlet air filters at regular intervals to avoid high-pressure drops. Manometers or differential pressure gauges across filters may be provided for monitoring pressure drops so as to plan filter-cleaning schedules.

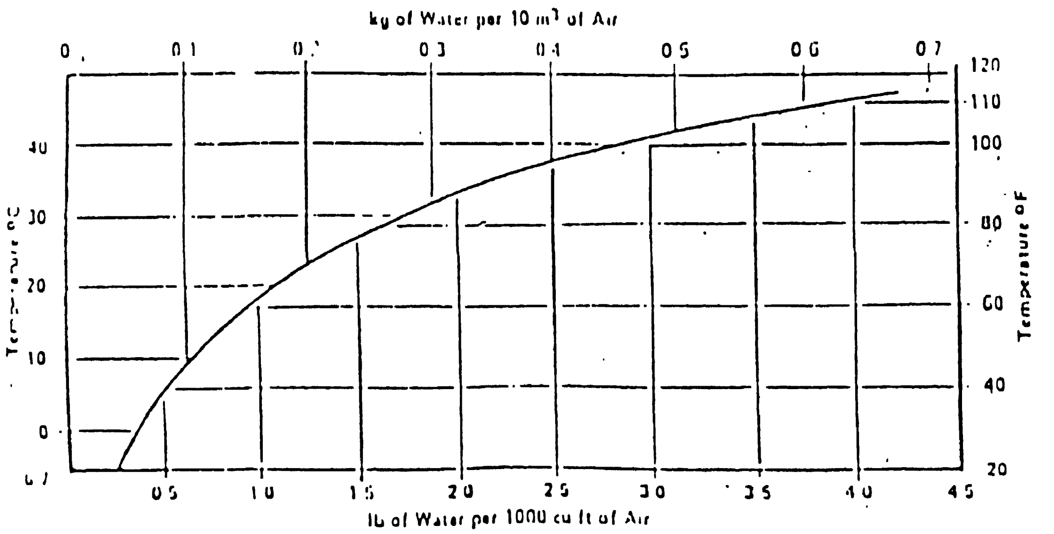
Dry air intake

Atmospheric air always contains some amount of water vapour, depending on the relative humidity, being high in foggy or rainy weather. The moisture level will also be high if air is drawn from a damp area, cooling tower exhaust and air conditioner warm outlet air.

Table 3.4 : Moisture Levels at Various Humidity Levels

% Relative Humidity	Kg of water vapour compressed per hour for every 1000 m^3/min. of air at 30°C
50	27.60
80	45.00
100	68.22

Fig. 3.1 : Water Carrying Capacity of Air



It is desirable to draw in air with a low relative humidity, as otherwise, energy is consumed to compress the water vapour in the air and again to condense and drain the moisture from inter and after coolers. The moisture-carrying capacity of

air increases with a rise in temperature and decreases with increase in pressure. Fig. 3.1 quantifies the water carrying capacity of air for different temperatures.

Pre-cooled Air intake

By cooling the air entering the compressor, the efficiency of the compressor can be improved. This cooling, usually to 25°C is achieved by refrigeration. As the temperature of air is reduced, its volume decreases and a greater mass of air is available for the given compressor. Therefore, due to pre-cooling either more air is delivered for a given power input or the power input is reduced for a required volumetric flow rate. Using pre-cooled dry air can save about-20 - 30 % of compressor power requirement. Also,

- *The moisture present in inlet air is condensed out giving dry air for compression and saving energy which would otherwise be used for compressing water vapour.*
- *The dust present in the air is entrained in the ice during freezing. This acts as a filter eliminating the need for a conventional filter and its inherent flow resistance, leading to further energy savings as well as capital cost savings.*
- *After-coolers and dryers are also eliminated as the pre-cooler performs their functions. This represents another capital cost saving as well as an additional energy saving device.*

Elevation

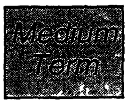
The altitude of a place has a direct impact on the volumetric efficiency of the compressor. The effect of altitude on volumetric efficiency is given below:

Table 3.5 : Effect of Altitude on Volumetric Efficiency

Altitude Metres	Barometric Pressure Mbar	Percentage relative volumetric efficiency compared with sea level	
		At 4 bar	At 7 bar
Sea Level	1013	100.0	100.0
500	945	98.7	97.7
1000	894	97.0	95.2
1500	840	95.5	92.7
2000	789	93.9	90.0
2500	737	92.1	87.0

It is evident that compressors located at higher altitudes consume more power to achieve a particular delivery pressure than those at sea level, as the compression ratio is higher.

3.3 Cooling Water Circuit



Most of the industrial compressors are water-cooled, wherein the heat of compression is removed by circulating cold water to cylinder heads, inter-coolers and after-coolers. The resultant warm water is cooled in a cooling tower and circulated back to compressors. The effect of cooling tower performance, total dissolved solids (TDS) in cooling water, pumps and fans on compressor performance is discussed below.

Cooling tower performance

The main purpose of a cooling tower is to reduce the inlet warm water temperature to near the wet bulb temperature of ambient air. Cooling towers are generally designed to have an approach temperature of 2 to 5(C depending upon the type of cooling tower. In practice, because of microbial growth, scale formation, corrosion and improper maintenance, the intimate contact between air and water is disturbed, resulting in high temperature outlet water which will affect compressor inter cooler effectiveness and compressor performance. Proper maintenance of cooling tower is very important to achieve the desired approach temperature.

Effect of air wet bulb temperature on cooling tower performance

The cooling tower performance is affected by atmospheric conditions - particularly by the wet bulb temperature of inlet air. In a given location, the wet bulb temperature changes throughout the year, reaching its peak value only occasionally. It would, therefore, be uneconomical to operate the tower designed on the basis of the maximum wet bulb temperature. A compromise between peak and average conditions has to be adopted. While designing or selecting a cooling tower, "5 %" wet bulb temperature is used which is, the wet bulb temperature not exceeded more than 5% of the total number of hours during summer months. This is estimated from the study of local meteorological data.

Cooling tower pump

Cooling water is supplied to compressors through centrifugal pumps at a particular pressure and flow rate. Any change in water flow rate or pressure will affect the compressor performance. High efficiency pumps and motors have to be selected, as they run continuously. Inter connecting pipe lines, inter-coolers,

and after-coolers have to be selected or designed for minimum pressure drop. Generally pumps in a central compressor house are over-designed for safety reasons, and are capable of catering to more than one compressor. During lean seasons and night shift, only one or two compressors are in operation but cooling water is circulated through even in idle compressors. To avoid this waste of water supply, idle compressors should be closed or a water pressure switch fixed in the water line so that compressor can be tripped off whenever the cooling water pressure falls below a pre-set value.

Cooling tower fans

Cooling tower fans are provided to facilitate more air throughput thus increasing cooling tower efficacy. A malfunction of fan will result in less air to water ratio, change in air distribution pattern etc., which will affect the cooling tower performance. Hence, proper fan maintenance and fan energy management has to be adopted for lower energy consumption.

- *Once the cooling water temperature approaches the wet bulb temperature of ambient air, the cooling tower fan can be switched off or operated intermittently by providing a interlock between water outlet temperature and fan operation.*
- *If two speed motors are used the cooling tower fan power requirement can be reduced substantially, whenever the ambient wet bulb temperature decreases.*
- *Automatic variable pitch propeller type fans and inverter type devices can be incorporated to permit variable fan speeds. These can track the cooling load for a constant outlet water temperature.*
- *Heavy fan blades made up of metals can be replaced with light weight, and aerodynamically designed blades such as FRP to reduce the initial torque required and the power consumption.*
- *Speed control of cooling tower fans by fluid-coupling drives can decrease power consumption in motors.*

Cooling Water TDS

In most of the installations, raw water with high TDS is used for compressor cooling. Because of inadequate attention to water quality, the TDS levels may shoot up to unacceptable levels, due to water loss through evaporation, drift and other entertainment losses. This leads to increase of scaling in cylinder heads, inter-coolers and after-coolers, which reduces heat exchanger efficacy and compressor capacity. The scaling in compressor and inter connecting pipelines

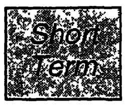
not only reduce its effectiveness but also increases pressure drop and thus, water pumping power.

Table 3.6 : Effect of Scaling on Pressure Drop and Inner Pipe Diameter

Scaling Thickness (mm)	Inside Diameter Reduced		Pressure Drop
	From (mm)	To (mm)	
0.4	64	63.2	6
0.8	64	62.4	14
1.2	64	61.6	21
4.7	64	54.6	134

Use of treated water or purging a portion of cooling water periodically can maintain TDS levels within acceptable limits. It is better to maintain the water pH by addition of chemicals, and avoid microbial growth by addition of fungicides and algaecides.

3.4 Efficacy of Inter and After-Coolers



Inter-coolers are provided between successive stages of a multi-stage compressor to cool the air, reduce its specific volume and condense out excess water. This reduces the power requirement in consecutive stages. Ideally, the temperature of the inlet air at each stage of a multi-stage machine should be the same as it was at the first stage. This is referred to as "perfect cooling". But in actual practice, because of fouled heat exchangers, due to scaling of dissolved solids in cooling water, the inlet air temperatures at subsequent stages are higher than the normal levels resulting in higher power consumption, as a larger volume is handled for the same duty. A case study discusses the practical application of this opportunity.

Table 3.7 : Effect of Inter-stage Cooling on Specific Power Consumption of a Reciprocating Compressor

Details	Imperfect cooling	Perfect cooling	Chilled water cooling
I stage inlet temp°C	21.1	21.1	21.1
2 Stage inlet temp°C	26.6	21.1	15.5
Capacity (m^3/min)	15.5	15.6	15.7
Shaft Power (kW)	76.3	75.3	74.2
Specific energy consumption kW/(m^3/min)	4.9	4.8	4.7
Percent change	+ 2.1	-	-2.1

It can be seen from the table that an increase of 5.5°C in the inlet to the second stage results in a 2% increase in the specific energy consumption. Use of cold water reduces power consumption. However, use of very cold water could result in condensation of moisture in the air leading to cylinder damage. An after-cooler is located after the final stage of the compressor to reduce air temperature and water content, as far as possible, before air enters the receiver. As time passes, dissolved solids in the cooling water coat the after-coolers, thereby reducing the heat transfer effectiveness. So, fouled after-coolers allow warm, humid air into the receiver, which causes more condensation in air receivers and distribution lines, which in consequence, leads to increased corrosion. Periodic cleaning of both heat exchangers and cylinder heads are therefore necessary.

Table 3.8 : Cooling Water Requirement

Compressor Type	Minimum quantity of cooling water required for 2.85 m^3/min FAD at 7 bar (lpm)
Single-stage	3.8
Two-stage	7.6
Single-stage with after-cooler	15.1
Two-stage with after-cooler	18.9

Inter-cooler and after-cooler efficacy also depends upon the quantity of cooling water circulated through the heat exchanger.

3.5 Pressure Settings

Reducing delivery pressure :

Opera-tional / Short Term

The power consumed by a compressor depends on its operating pressure and rated capacity. They should not be operated above their optimum operating pressures as this not only wastes energy, but also leads to excessive wear, leading to further energy wastage. The volumetric efficiency of a compressor is also less at higher delivery pressures. The possibility of down setting the delivery pressure should be explored by careful study of pressure requirements of various equipment, and the pressure drop in the line between the compressed air generation and utilisation points. The pressure switches must be adjusted such that the compressor cut-in and cuts-off at optimum levels.

Table 3.9 : Power Reduction through Pressure Reduction

Pressure Reduction		Power Reduction (%)		
From (bar)	**To (bar)**	**Single-stage water-cooled**	**Two-stage water-cooled**	**Two-stage air- cooled**
6.8	6.1	4	4	2.6
6.8	5.5	9	11	6.5

A reduction in the delivery pressure of a compressor would reduce the power consumption. This has been practically achieved, as discussed in the relevant case study.

Compressor modulation by optimum pressure settings

Very often in an industry different types, capacities and makes of compressors are connected to a common distribution network. In such situations, proper selection of a right combination of compressors and optimal modulation of different compressors can conserve energy. Where more than one compressor feeds a common header, compressors have to be operated in such a way that the cost of compressed air generation is minimal.

If all compressors are similar, the pressure setting can be adjusted such that only one compressor handles the load variation, whereas the others operate more or less at full load.

If compressors are of different sizes, the pressure switch should be set such that only the smallest compressor is allowed to modulate. If different types are operated together, for example, both reciprocating and screw compressors, the reciprocating compressor must be allowed to modulate, while keeping the screw compressor at full load always as its part load operation consumes more power. In general, the compressor with lower no-load power consumption must be modulated. Compressors can be graded according to their specific energy consumption, at different pressures and energy efficient ones must be made to meet most of the demand.

3.6 Capacity Control of Compressors

In many installations, the use of air is intermittent. Therefore, some means of controlling the output of the compressor is necessary. This is achieved by regulation of pressure, volume, temperature or some other factors. The type of capacity control employed has a direct impact on the compressor power consumption. Some control schemes commonly used are discussed below :

On/off control

Automatic start and stop control, as its name implies, starts or stops the compressor by means of a pressure activated switch as the air demand varies. This is a very efficient method in controlling the capacity of compressor, where the motor idle-running losses are eliminated, as it completely switches off the motor when the set pressure is reached. This is suitable for small compressors (less than 10 kW).

Load and unload

This is a two-step control where compressor is loaded when there is air demand and unloaded when there is no air demand. During unload, the reciprocating compressor motor runs without air compression, thereby consuming only 10-20% of the full load power. In screw compressors, the unloading is achieved by closing the inlet valve. The idling power is about 50 to 70% of the full load power.

Multi step control

Motor-driven reciprocating compressors above 75 kW are usually equipped with a multi step control. In this type of control, unloading is accomplished in a series of steps, varying from full load down to no-load. A relevant case study has been appended for this opportunity.

Table 3.10 : Power Consumption of Reciprocating Compressor at Various Loads

Load %	Power consumption as % of full load power
100	100
75	76-77
50	52-53
25	27-29
0	10-12

Five-step control (0%, 25%, 50%, 75% & 100%) is accomplished by means of clearance pockets. In some cases, a movable cylinder head is provided for variable clearance in the cylinder.

Throttling Control

This kind of control is achieved using an inlet valve or a variable-displacement slide valve and is suitable for screw compressors where the capacity can be varied from 40 to 100%. The variable displacement method reduces the volume of air delivered by venting air from a variable portion of the helical screw length to the inlet side of the compressor. The variable displacement method is more efficient than the inlet valve.

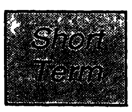
The output of centrifugal compressors can be controlled using variable inlet guide vanes to throttle discharge pressure. However, another efficient way to match compressor output to meet varying load requirements is by speed control.

Table 3.11 : Typical Part Load Gas Compression Power Input for Speed and Vane Control of Centrifugal Compressors

System Volume	Flow % Speed Control	Power Input (%) Vane Control
111	120	-
100	100	100
80	76	81
60	59	64
40	55	50
20	51	46
0	47	43

At low volumetric flow (below 40%), vane control may result in lower power input compared to speed control due to low efficiency of the speed control system. For loads more than 40%, speed control is recommended.

3.7 Avoiding Misuse of Compressed Air



Misuse of compressed air, purposes like for body cleaning, liquid agitation, floor cleaning, drying, equipment cooling and other similar uses must be discouraged. Wherever possible, low pressure air from a blower should be substituted for compressed air, for example secondary air for combustion.

3.8 Replacing V Belts with Synthetic Flat Belts

The advisability of replacing V-belts, in compressor drives, by synthetic flat belts has been hotly debated. Synthetic flat belts do not have to wedge-in & out of the pulley grooves, as do V-belts and this results in power saving. Though

manufacturers of flat belts claim savings up to 13% over V-belts, the margin of savings also depend upon the condition of existing V-belts/pulley adjustments and the loading conditions. Savings ranging from 3 to 5% have been observed after retrofitting with flat belts. In order to cut down on the capital cost involved in the replacement and to achieve a short payback period, the filling of grooves of the V-belt pulley with epoxy resin reinforced with nylon thread and 'M-seal' can be tried out. In such a replacement, the dynamic balance of the pulley and slip offered by the surface should be kept in mind. Retrofitting done by synthetic flat belt manufacturers along with good after-sales-service, can result in tangible savings and satisfied users. A practical energy audit has identified this opportunity for significant savings, as discussed in the case study later.

3.9 Avoiding Air Leaks and Energy Wastage

Short / Medium Term

The major opportunity to save energy is in the prevention of leaks in the compressed air system. Leaks frequently occur at air receivers, relief valves, pipe and hose joints, shut off valves, quick release couplings, tools and equipment. In most cases, they are due to poor maintenance and sometimes, improper installation in underground lines.

Air Leakage through Different Orifices

The following table gives the amount of free air wasted for different nozzle sizes and pressures :

Table 3.12 : Discharge of Air through Orifice (C_d = 1.0)

Gauge Pressure Bar	0.5 mm	1 mm	2 mm	3 mm	5 mm	10 mm	12.5 mm
0.5	0.06	0.22	0.92	2.1	5.7	22.8	35.5
1.0	0.08	0.33	1.33	3.0	8.4	33.6	52.5
2.5	0.14	0.58	2.33	5.5	14.6	58.6	91.4
5.0	0.25	0.97	3.92	8.8	24.4	97.5	152.0
7.0	0.33	1.31	5.19	11.6	32.5	129.0	202.0

Cost of Compressed Air Leakage

It may be seen from the given table that any expenditure on sealing leaks would be paid back through energy saving :

Table - 3.13 : Cost of Air Leakage

Orifice size mm	kW Wasted	*Energy Waste (Rs/year)
0.8	0.2	6,400
1.6	0.8	25,600
3.1	3.0	96,000
6.4	12.0	3,84,000

* based on Rs.4.0/kWh; 8000 operating hours; air at 7.0 bar.

A simple method of measuring the total leakage of the system, which should be part of the planned maintenance programme, has already been explained in the quantification of compressed air leakage. A case study illustrates how leakage of 53 % in the compressed air system was brought down to within 15 % for substantial savings.

3.10 Need for Capacity Assessment

Short / Medium Term

The compressor capacity is expressed in terms of quantity of free air delivered at a particular pressure. Due to ageing of the compressors and inherent inefficiencies in the internal components, the free air delivered may be less than the design value, despite adherence to good maintenance practices. Sometimes, other factors such as poor maintenance, fouled heat exchanger and effects of altitude also tend to reduce free air delivery. In order to meet the air demand, the inefficient compressor may have to run for more time, thus consuming more power than actually required.

The power wastage depends on the percentage deviation of FAD capacity. For example, a worn out compressor valve can reduce the compressor capacity by as much as 20 percent. A periodic assessment of the FAD capacity of each compressor has to be carried out to check its actual capacity. If the deviations are more than 10%, corrective measures should be taken to rectify the same.

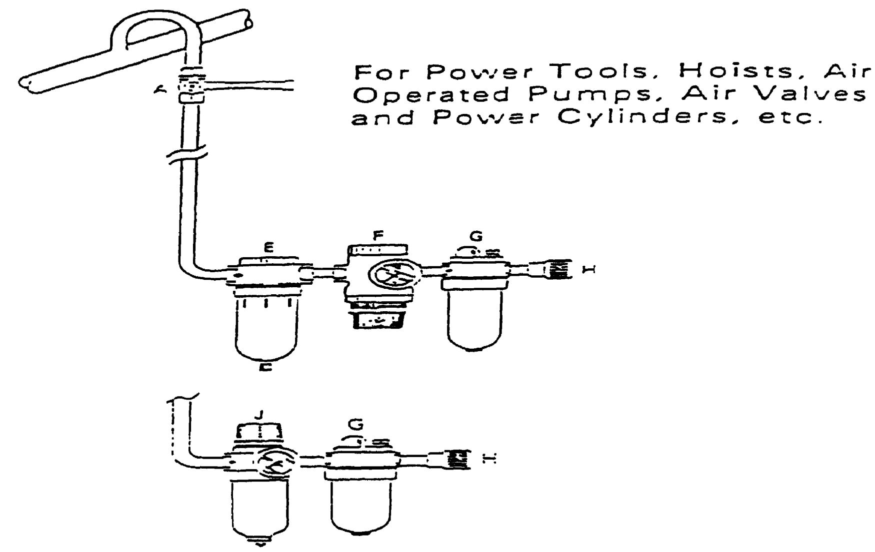
3.11 Line Moisture Separator and Traps

Short / Medium Term

Although, in an ideal system, all cooling and condensing of air should be carried out before the air leaves the receiver, this is not very often achieved in practice. The amount of condensation, which takes place in the lines, depends on the efficiency of moisture extraction before the air leaves the receiver and the temperature in the mains itself. In general, the air main should be given a fall of not less than 1 m in 100 m in the direction of air flow, and the distance between drainage points should not exceed 30 m.

Drainage points should be provided using equal tees, as it assists in the separation of water. Whenever a branch line (Figure - 3.2) is taken off from the mains it should leave at the top so that any water in the main does not fall straight into the plant equipment. Further, the bottom of the falling pipe should also be drained.

Fig. 3.2 : Typical Air Off Take Point Requiring Lubrication



Key
A — Isolating Ball Valve
E — Filter
F — Regulator and Pressure Gauge
G — Lubricator
H — Female Quick Release Coupling
J — Combined Filter/Regulator and Pressure Gauge (Air Transformer)

For most applications, much of this condensed moisture can be removed by fitting a separator (Figure - 3.3) in the distribution mains. An automatic device such as a trap (Figure - 3.4) can be used to drain water from different parts of the compressed air installation.

Fig. 3.3 : Separator

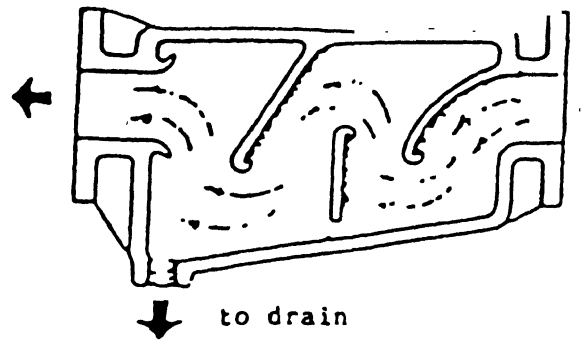
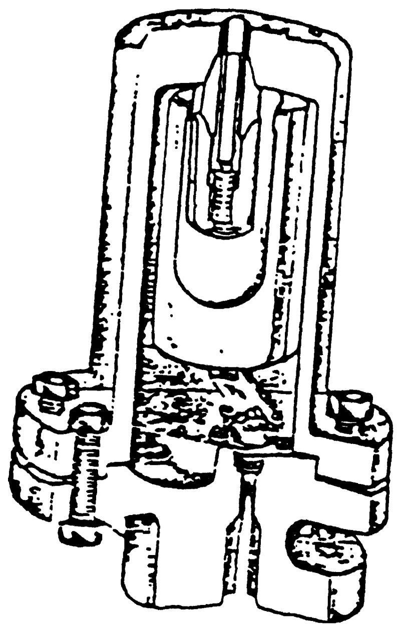
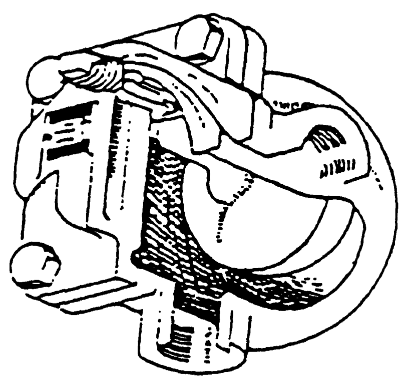


Fig. 3.4 : Drain Trap





Drain Traps

There are basically two types of traps available : Mechanical and electrical/electronic.

Mechanical:

Thermodynamic trap: These are similar to the traps for steam application but with slight difference in construction. They open and close depending on the quantity of moisture coming out. However, they waste some compressed air during opening. They handle oil and emulsion better than float operated traps.

Float operated trap: These are similar to steam traps and work on the principle of branch of float, operating an outlet valve with continuous discharge. However, their drawback is that the valve gets clogged due to the accumulation of oil and other pipe dust. The emulsion formation between oil and water also affects its operation. Installing a strainer before the trap can help to some extent.

Inverted Bucket trap: This is used when the pressures are high - (up to 62 bar). These are much more rugged than float operated traps.

Electrical/Electronically operated :

These are timer-operated solenoid valves, that open at regular intervals for a pre fixed time and allow the water accumulated at the bottom of receivers and main lines to drain out. However they need electric supply to operate.

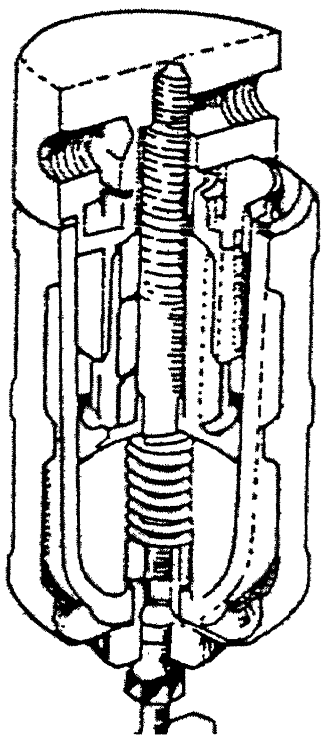
Compressed air filter

Although some water, oil and dirt are removed by the separators and traps in the mains, still some of it is always left, which is being carried over. Moreover, pipe systems accumulate scale and other foreign matters, such as small pieces of gasketing material, jointing compounds and so on. Burnt compressor oil may also be carried over in pipe work, and this, with other contaminants, forms a gummy substance. To remove these, all of which are liable to have deleterious effects on pneumatic equipment, the air should be filtered as near as possible to the point of use. One such filter is shown in Figure - 3.5. Water and oil collected in the filter sump must be drained off because, if its level is allowed to build up, then it is forced through the filter element into the very system it is designed to protect.

Regulators

In many instances pneumatic operations are to be carried out at a lower pressure than that of the main supply. For these applications, pressure regulators are required to reduce the pressure to the required value and also to ensure that it remains reasonably constant at the usage point. Pilot operated type regulators are energy efficient than direct-acting and self-relieving regulators. In the self-relieving type, a small relief valve is provided which allows excess air to bleed away, should the down stream pressure exceed the set value. It is suitable for applications where the control pressure has to be varied periodically.

Fig. 3.5: Air Filter



Lubricators

Medium / Long Term

Where air is used to drive prime movers, cylinders and valves, they should be fitted with a lubricator. Essentially, a lubricator is a reservoir of oil and has been designed so that when air is flowing, a metered amount of oil is fed in mist form into the air stream. This oil is carried with the motive air, to the point of use to lubricate all moving parts. All lubricators require a certain minimum rate of air

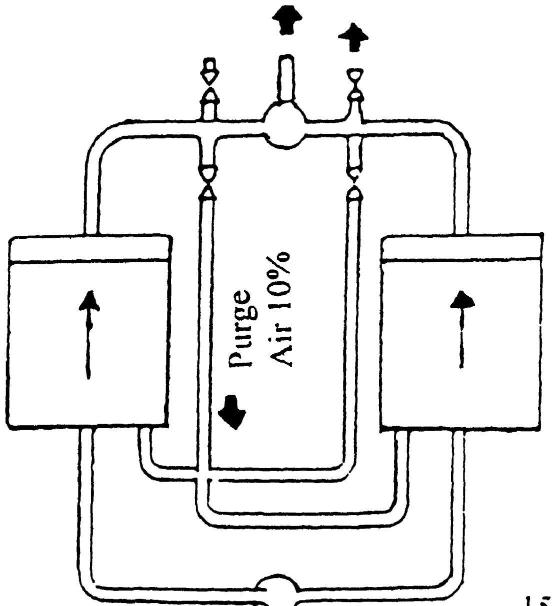
flow to induce oil into the air stream. Their design should be such that once the air flow is more than this minimum rate, they give satisfactory lubrication without causing an excessive pressure drop. Light, free-fogging, lubricating oil with a high velocity index and without lead additives is suitable for lubrication. The ratio of oil to air can be decided experimentally. A rough guide is, one drop of oil per minute for every 5 dm^3/s of free air at 5.5 bar pressure.

It is advisable to fix filters, regulators and lubricators as close as possible to the equipment being served. Where lubricators are used to provide oil for linear actuators or when the direction of air flow is reversed, the volume of pipework between the lubricator and cylinder should not exceed 50% of the volume of free air used by the cylinder per stroke.

3.12 Air Dryers

There are certain applications where air must be free from moisture and have a lower dew point. This calls for more sophisticated and expensive methods to lower the dew point of compressed air. Three common types of air dryers used are heat-less (adsorption), absorption and chiller dryers. They produce dry air with 10°C to -40°C dew point, depending on the type of dryers.

Fig. 3.6 : Absorption Dryer



Adsorption dryers

This type of dryer consists of two pressure vessels filled with a water-adsorbing chemical such as silica gel or activated alumina.

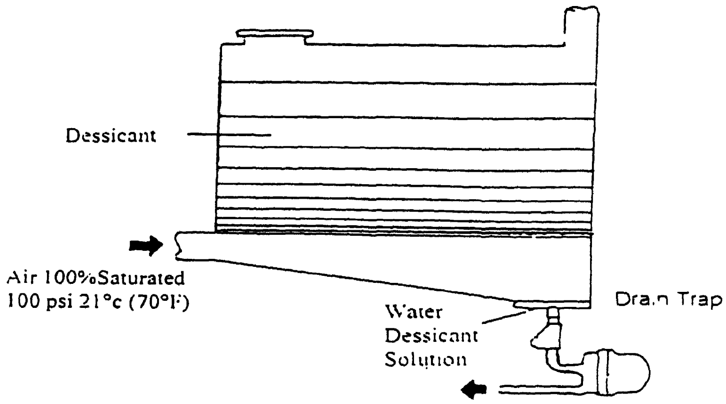
One of the pressure vessels is in operation at any given time. The compressed air with moisture, from the compressor, is passed through one of the pressure vessels, until the chemical is saturated with water, whilst, the other vessel is regenerated by heat or purging of about 10 percent of the dry air. An automatic system alternates the chambers.

Absorption or Deliquescent Dryers

In this type of dryer the wet air is passed through the chamber containing water-absorbing chemical or desiccant, which absorbs the water vapour and forms a solution.

This solution has to be discharged periodically by using a drain trap and the level of the desiccant then requires topping up.

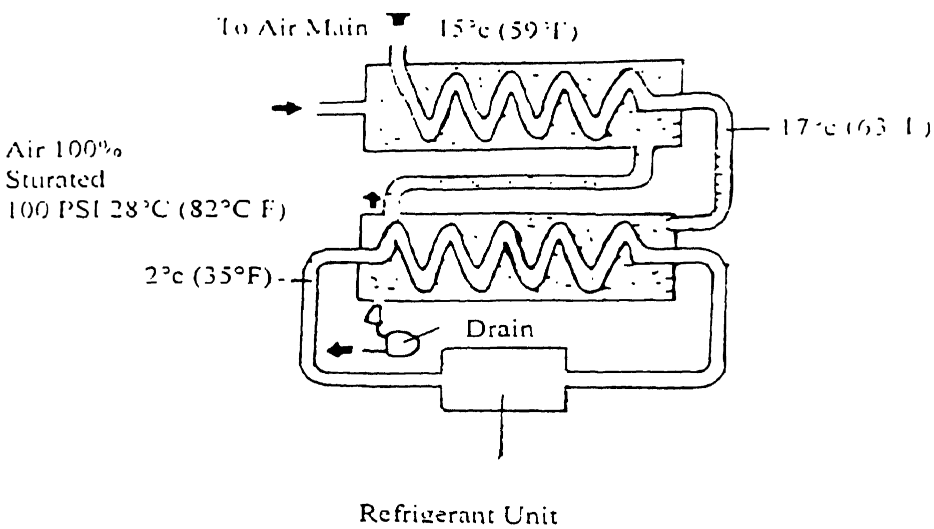
Fig 3.7 : Absorption Dryer



Refrigerant or Chiller Dryers

The wet air is passed through a mechanical refrigeration system where the air is cooled to pressure dew point of 1 to 4°C of the water vapour, thus lowering dew point to about -15°C.

Fig. 3.8 : Refrigerant Dryer



There exists a facility to pre-cool wet air entering into the dryer by the outgoing cold dry air.

Table 3.14 : Comparison of Dryers

Type	Dew Point °C	First Cost	Operating Cost	Power Consumption (kW) for 1000 m^3/hr
Chiller (Refrigeration)	-15	Low	Low	2.9
Desiccant Regenerative (Air Purging)	-20	Low	High	20.7
Desiccant Regenerative (External heating with steam or electricity - reduced air purging)	-40	Medium	Medium	18.0
Desiccant Regenerative (External heating of ambient air, no air loss)	-40	High	Low	12.0

All these units incur running costs of some sort, whether it is hot compressed air for purging, steam or electrical power to reactivate the chemicals.

3.13 Air Receiver Installation

Medium / Long Term

The main purpose of a receiver is to act as a pulsation damper, allowing intermittent high demands for compressed air to be met from a small compressor set, resulting in lesser energy consumption.

The air receiver should be generously sized to give a large cooling surface and even out the pulsation in delivered air pressure from a reciprocating compressor. A simple formula often quoted for air receiver size is to take a value equal to one minute's continuous output of the compressor. However, this should be considered indicative of the minimum size of receiver. A better suggestion is to estimate the peak air consumption likely and allow for the maximum pressure drop that is acceptable at this peak load.

$$\text{Receiver capacity in } m^3 = \frac{m^3 \text{ of free air volume required}}{\text{permissible pressure drop in bar}}$$

If peaks cannot be quantified, another approximation can be to size the receiver volume to be 5% of the rated hourly free air output. Providing an air receiver near the load end, where there is sudden high demand lasting for a short period, would avoid the need to provide extra capacity.

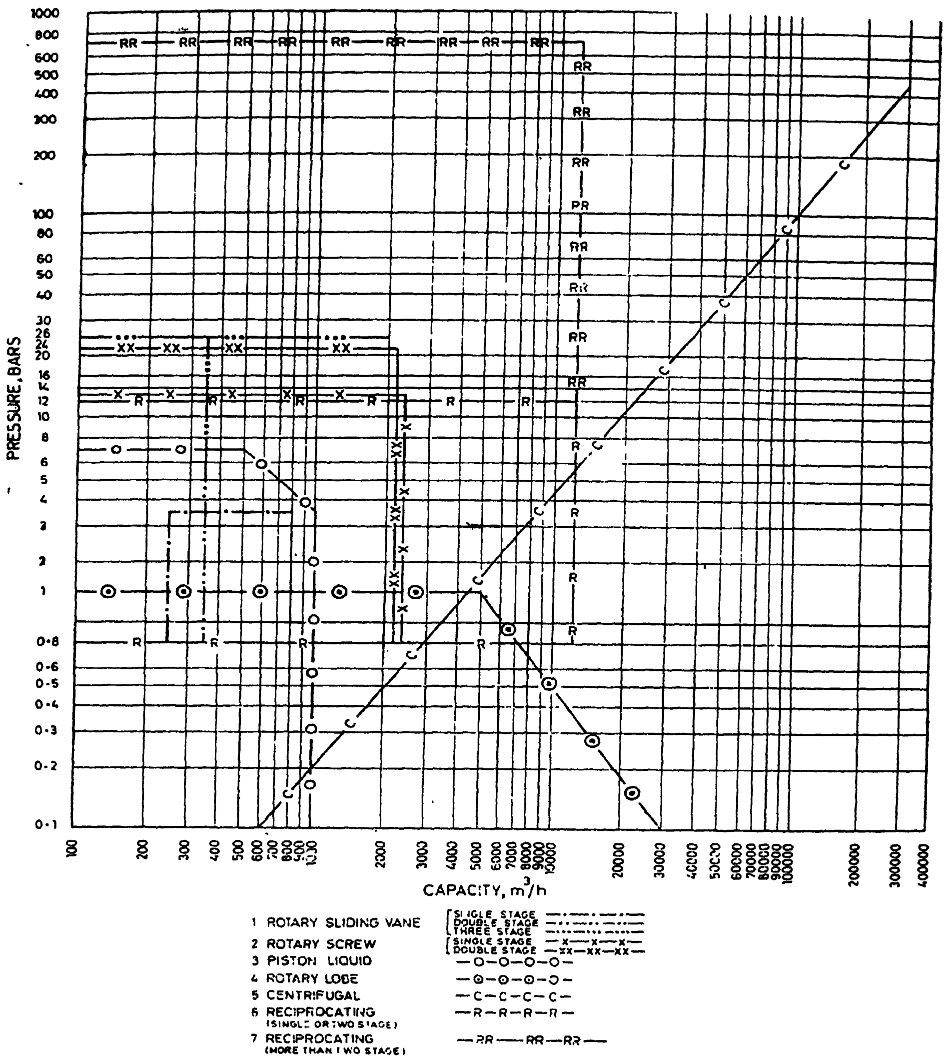
3.14 Compressor Selection

In general, compressors are selected on the basis of initial cost, not on the basis of life-time cost. The latter takes into account, not only the fixed cost, but also variable costs such as energy cost, maintenance cost and supervision cost. In fact, the selection of the right type and capacity of a compressor for a particular application is rather difficult, as it involves consideration of so many intricate factors such as:

- Future expansion requirements.
- Maximum and minimum pressures required.
- Type of cooling required.
- Space requirement.
- Type of capacity control.
- Running cost.
- Initial cost
- Safety aspects.

However, the following general guidelines may be complied with, while, sizing and choosing a compressor.

Fig 3.9 : Selection Chart for Air Compressors



Specific Speed

The specific speed, which depends on the basic design of compressors, is a useful parameter in selecting an efficient compressor. The specific speed is calculated as:

$N_s = N.Q^{1/2}\ H^{3/4}$

Where

N is the rotational speed in rpm.

Q is the flow in scfm
H is the adiabatic head in feet.
N_s is the compressor specific speed.

The specific speed can be calculated at any desired speed; and the efficacy of this method is largely dependent on the accurate determination of the flow required. Most processes have varying load requirements. At a minimum, the average, minimum and maximum flow should be determined based on process requirements. The load factor, which is the ratio of the actual demand of pneumatic equipment or any other end-uses to their rated requirement, should be established to determine the flow requirement. In selecting compressor capacity, the flow should be converted to standard units.

Within the broad categories of compressors available, the required capacity of the air delivery and the pressure at which it is required provide a basis for selecting the specific type of compressor. A large number of additional factors can affect the choice of a compressor for a particular application. Among these are the expected ranges of mass and volumetric flow. These vary with process requirements such as continuous or batch operation and variation in air demand during operation. They are also influenced by variations in inlet temperature, pressure, discharge pressure and flow of cooling fluid. Presence of vapours, liquids or dust at the suction all influences the selection of the compressor and the auxiliary system.

Single or Multistage Compressor

Single stage compressors consume more power than multistage compressors for the same output and operating pressure, as they follow adiabatic compression path whereas multistage compressors are made to approach Isothermal compression path, wherein air is cooled between stages, reducing power consumption.

Table 3.15 : Power Requirement

Gauge pressure (bar)	Theoretical adiabatic power kW/100 dm^3 of free air		
	Single stage	Two stage	Three stage
0.5	4.0	-	-
1.0	7.5	-	-
2.5	15	14	-
5.0	23	20	19
7.0	28	24	22
10.0	34	28	27
14.0	40	32	30

The difference in power consumption is small at lower pressures, but becomes significant at higher pressures. A smaller capacity single-stage air-cooled compressor is still preferred, because of lower investment and maintenance costs. Multistage water-cooled compressors are favoured for high capacity and pressure, as the additional investment is paid back normally within 3 years. Even in multistage compressors the air-cooled type consume more power than the water cooled one, as the temperature of ambient air used as the cooling medium is a few degrees higher than cooling tower water temperature. The practical aspects of this have been discussed in the relevant case study.

Capacity and Size

Compressor selection should be based on the pressure required and the average and maximum air requirement with the following guidelines :

- *Small size centrifugal, rotary screw and vane compressors are less energy - efficient.*
- *Rotary vane compressors for ratings of 93 kW and over will consume 6-20 % more energy than reciprocating compressor having the same capacity.*

Table 3.16 : General Selection Criteria for Compressors

Type of Compressor	Capacity (m3/h)		Pressure (bar)	
	From	To	From	To
Roots compressor - single stage	100	30,000	0.1	1
Reciprocating				
- Single /Two Stage	100	12,000	0.8	12
- Multi Stage	100	12,000	12.0	700
Screw				
- Single Stage	100	2,400	0.8	13
- Two Stage	100	2,200	0.8	24
Centrifugal	600	300,000	0.1	450

A practical case study discusses this optimisation of compressor selection.

Capacity Utilisation

In many installations, the use of air is intermittent. This means the compressor will be operated on low load or no load condition, which increases the specific power consumption per unit of air generated. Hence, for optimum energy consumption, a proper compressor capacity control should be selected. The nature of the control device depends on the function to be regulated. Regulation of pressure, volume, temperature or some other factor determines the type of regulation required and the type of the compressor drive.

A variable speed drive is suitable for compressors driven by steam piston, steam turbines, gas engines, diesel engines etc. Unloading devices are suitable for reciprocating compressors. During unloaded condition, reciprocating compressors consume about 10 - 12 % of the full load power, whereas screw compressors consume about 25 - 30 % of full load power. Other types of controls are discussed in compressor capacity control. Screw and centrifugal compressors are suitable for base load or full load applications, but not desirable for part load operations, where slide vane or inlet guide vane controls are used, as specific energy consumption increases.

Efficiency

Compressor efficiency is sometimes expressed in terms of adiabatic or isothermal efficiency, depending on the type of compressor. Adiabatic efficiency is used for centrifugal compressors, whereas isothermal efficiency is used for reciprocating compressors. These are computed as the adiabatic and isothermal power, respectively, divided by the actual power consumption. When comparing different machines, a higher value of efficiency based on a particular definition may result in poorer performance than a lower value based on a different definition. Manufacturers generally provide the adiabatic (theoretical) horsepower required for compression. The actual power intake would be slightly higher, because of mechanical losses. For practical purposes, the most effective guide in comparing compressor efficiencies is the specific power consumption for different compressors that would work on identical loads.

3.15 Efficient Air Distribution

Ring main system

After generating compressed air, it has to be conditioned (removal of oil, moisture and dirt) and transported to the end-user points without much drop in pressure, either by a ring main or a semi ring-main system. Generally ring main is the best arrangement for a compressed air system, as it maintains equal pressure throughout the distribution system. It also makes the alteration or extension of the existing system easier with lesser drop in pressure.

Mains air pressure reduction

It is often necessary to reduce the mains pressure when supplying groups of plants or complete workshops. This requires a pressure reducing valve of large capacity and good flow characteristics. In these circumstances, a pressure reducing station may be used.

If the low pressure air requirement is considerable, it is advisable to generate low pressure and high pressure air separately, and feed to the respective sections instead of reducing the pressure through pressure reducing valves, which invariably waste energy.

Minimum pressure drop in air lines

The air mains and their associated branches, hoses, couplings and other accessories offer considerable opportunities for energy conservation.

Table 3.17 : Energy Wastage due to Smaller Pipe Diameter

Pipe Nominal Bore (mm)	Pressure drop (bar) per 100 metres	Equivalent power losses (kW)
40	1.80	9.5
50	0.65	3.4
65	0.22	1.2
80	0.04	0.2
100	0.02	0.1

Excess pressure drop due to inadequate pipe sizing, choked filter elements, improperly sized couplings and hoses represent energy wastage. The above table illustrates the energy wastage, if the pipes are of smaller diameter.

Equivalent lengths of fittings

When long runs of distribution mains are involved, the pressure drops may be higher than acceptable levels; in such cases it is desirable to check for actual pressure drops.

Fig. 3.10 : Pressure Reducing Station

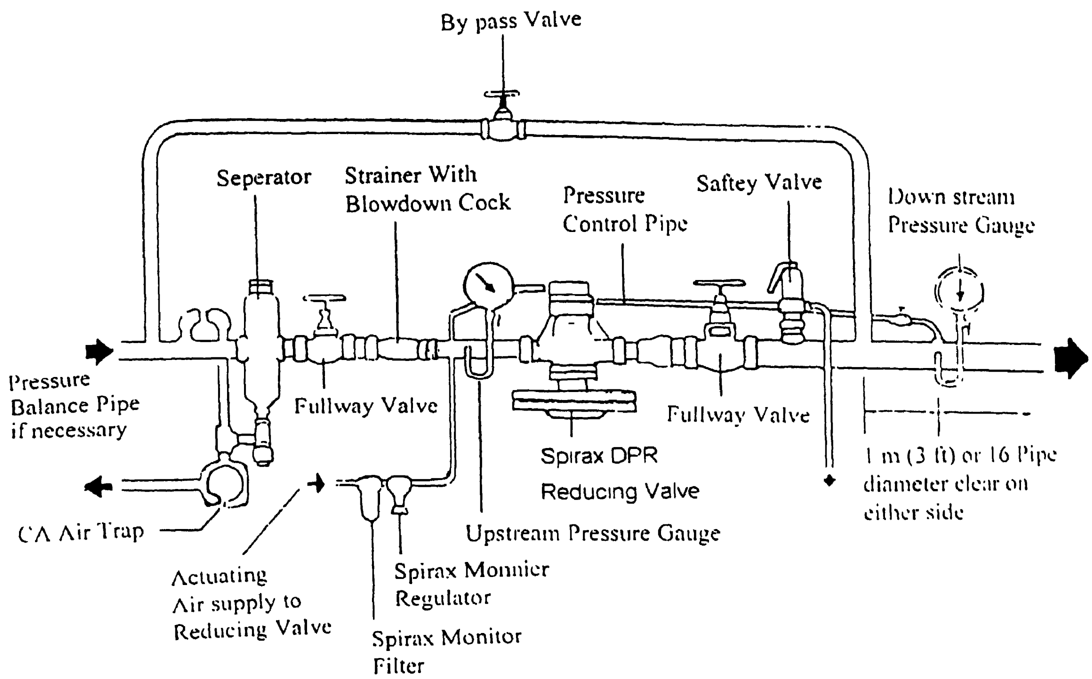


Table 3.18 : Resistance of Pipe Fittings in Equivalent Lengths (in metres)

Type of Fitting	Nominal Pipe Size in mm									
	15	20	25	32	40	50	65	80	100	125
Gate Valve	0.11	0.14	0.18	0.27	0.32	0.40	0.49	0.64	0.91	1.20
Run of Standard Tee	0.12	0.18	0.24	0.38	0.40	0.52	0.67	0.85	1.20	1.52
90° Long Bend	0.15	0.18	0.24	0.38	0.46	0.61	0.76	0.91	1.20	1.52
Elbow	0.26	0.37	0.49	0.67	0.76	1.07	1.37	1.83	2.44	3.20
Return Bend	0.46	0.61	0.76	1.07	1.20	1.68	1.98	2.60	3.66	4.88
Through Side Outlet of Tee	0.52	0.70	0.91	1.37	1.58	2.14	2.74	3.66	4.88	6.40
Globe Valve	0.76	1.07	1.37	1.98	2.44	3.36	3.96	5.18	7.32	9.45

Apart from air velocity, pipe diameter, pipe roughness, the various pipes fittings such as bends, valves, tees, etc., also affect pressure drops to a large extent. It

is a normal practice to convert various fittings into their equivalent lengths of straight pipe lines for calculation purposes. By adding the equivalent lengths to the actual length of pipe, the loss in that particular section can be easily found.

Line Sizing

It is normal practice to express the air demand of equipment and the plant in dm^3 / sec of free air. However, when the air gets compressed, the volume is much less. Therefore the pipe sizing is done by taking into account the reduced volume at that pressure.

Interconnecting pipes & branch lines

The interconnecting pipes and pipes leading to the equipment may be designed for higher velocity of compressed air. At 5.5 - 7 bar range, one can easily go upto 18 - 24 m/s. This is because, for short lengths of pipes, the pressure drops may not be significant. However, if the pressures are lower than 5.5 bar, then it is safer to keep the velocities lower.

3.16 Efficient Running of Air Driven Equipment

In a plant, equipment such as spray gun, cooling jet, hoists, control systems, etc., may operate with supply pressures in excess of those required for such operations. Considerable savings in air consumption, and thus energy, can be achieved by fitting a standard type of pressure regulator, to keep the pressure of the air being fed to the equipment to the required level.

Worn out seals and other moving parts of a pneumatic tool will inevitably lead to loss in operating efficiency with possible leakage of air.

The use of compressed air as a continuous source of motive power (pneumatic grinder, driller etc.,) should always be challenged and economics of using electricity directly for such application should be considered. For eg., pneumatic drills and grinders consume about 20 times more energy than motor driven tools.

Wherever possible, pneumatic conveying of materials must be replaced with mechanical conveying. For example pneumatic conveying of wood chips, powder etc, consumes about eight times more energy than belt or bucket conveying.

Blow guns operating at 6.2 bar for cleaning off swarf or moisture, use 3 times more air than when it is operated at 1.4 bar. A sand blast nozzle worn from 8 mm to 10mm consumes an additional 1.9 m^3/min of air. 10% increase in the operating pressure of an air tool reduces tool life by 14%. Spray guns operating at pressures more than 2-3 bar not only waste compressed air, but also paint. Air filters and oil separators installed in equipment must be serviced regularly to clean or renew the internal components, which gradually become choked with dirt and oil sludge, thus causing excessive pressure drop and energy wastage.

All pneumatic equipment should be properly lubricated to reduce friction, prevent wear of seals and other rubber parts thus preventing excessive air consumption or leakage.

3.17 Air Consumption of Pneumatic Tools and Appliances

The following table gives typical air requirements for some of the pneumatic equipment. The exact air requirement of a particular tool / equipment can be obtained from the manufacturer. In the absence of such data, values given in the table can be considered as approximate values for sizing a compressor :

Table 3.19 : Typical Air Consumption at 5.5 Bar Pressure

Type of Equipment	Size (mm)	Air consumption (dm^3/s) at 5.5 bar
Drills	7	4.7 - 7.5
	10	7.1 - 9.4
	13	11.8 -14.1
	25	28.3 - 37.7
	50	37.7 - 56.6
	75	47.2 - 61.4
Grinders for mounted prints		4.7 - 11.8
For armour mounted wheels	50	9.4 - 11.8
	150	23.6 - 28.3
Sanders & Polishers	Up to 7	4.7 - 21.1
Torque wrenches for nuts	13	4.7 - 7.1
	25	11.8 - 16.5
	38	18.9 - 26.0
		23.6 - 33.0
Screw drivers		3.3 - 11.8
Spray guns (at 3.4 bars)	Small	0.47 - 2.4
	Medium	2.4 - 5.7
		5.7 11.8
Blow guns		2.4
Air Motors		
Up to 1 BHP		14.1 16.5 / BHP
1 to 5 BHP		14.1 / BHP
Over 5 BHP		11.8 / BHP

The relevant IS standards for compressor pressures are discussed in Appendix2.

3.18 Compressor Motor

Electric motors are the prime movers for almost all compressors. Some special types of compressors are designed to operate with steam or diesel engines. Different types of induction motors have been widely used for compressors. Each has its own individual operating characteristics particularly suited to specific drive applications. The energy aspects related to compressor motors such as motor loading, PF, efficiency etc, are discussed below.

Motor loading

A compressor motor should be properly sized, so that the load on the motor and, hence, its efficiency are maximum. A compressor, either partially or fully unloaded still consumes 10 to 70% of its full load power. During no load condition, the motor power factor may be as low as 0.2, which makes motor operation inefficient. As far as possible, the compressor should be operated at full load so that operation at low power factor can be minimised.

Motor efficiency and PF correction

In regular plant operation, due to a number of factors, the capacity of the motors is higher than the requirement. Operating a high capacity motor at lower loads results in lower PF and reduced efficiency. The best method is to replace the motor with a suitably lower capacity motor. Capacitors may be installed to improve PF during low and no load operations. Another option is to run the motor in star mode, whereas the normal connection at rated voltage is delta. However, this should be thought of, only if the motor is always under-loaded below 40% of its rated capacity. For large turbo compressor installations, the provision of an over excited motor should be considered. This will improve the factory power factor considerably.

Soft Starters

Starting torque on reciprocating compressors can be high and thus careful selection of soft starters is necessary. Soft start feature provides a variable start time with minimum starting current thus eliminating surge currents and damage to the motors.

Dual speed motors

When the differential on-off pressure is low and the compressor is operates at optimum load conditions during its service-life, the option of a dual speed motor can be considered. Dual speed motors are an economical alternative for energy saving at off-load conditions. The economic payback is of course, a function of the specific compressor application and the motor speed ratios.

Variable speed motors

The ideal control for positive displacement compressors to conserve energy is by varying the speed. In steam or diesel engine compressors, this is straight forward, but not in AC induction motors. Developments in electronics and micro electronics have resulted in a more reliable control to allow a conventional AC induction motor to be operated in a variable speed mode at high efficiency. In the long term, such systems could become the standard for air compressors. A relevant case study has been discussed later in this manual.

3.19 Compressor Plant Maintenance

A well-maintained plant, not only delivers the rated capacity, but also leads to minimum energy consumption. The different parts in a compressor to be checked periodically are driving belts for tightness, valve gear, piston and piston rings of reciprocating compressors, vanes of rotary compressors and blades of turbo compressors. All instruments should be accurate, checked regularly and well maintained. Compressor's critical parameters such as pressure, air and cooling water temperatures, lubricating oil, motor current, etc., should be logged in a data sheet for analysis of its performance. Periodic cleaning of inter and after -coolers have to be carried out.

3.20 Maximising Compressed Air Utility through Micro-Processor Control Systems

Air systems, regardless of compressor design or capacity, can operate more efficiently and economically through the proper selection and optimisation of the control system used with the compressor unit.

Compressor control systems have long had the ability to monitor and adjust basic air compressor functions, associated with monitoring, loading, unloading and throttling. Now, some systems provide additional features such as trend analysis,

predictive maintenance schedules as well as remote monitoring and operations. The technologies that are currently available for compressor control systems and how they can increase operating efficiencies and reduce energy consumption are discussed below :

The compressor control systems function should be put on a demand cycle. If the demand for compressed air is steady and does not fluctuate, compressor controls simply match the capacity to the system demand. One basic form of compressor flow control is called inlet throttling, or inlet unloading.

Reducing the airflow is achieved by reducing the inlet opening through which the air enters the compressor. This, in turn, matches the compressor output to the system demand. Because system pressure acts as a demand indicator, throttling is usually controlled by system pressure. However, most air systems are more complex and demand is more variable than the one described.

Processes with complicated and varying demand cycles, which can include several compressors of different sizes and configurations to maintain system pressure, require a more sophisticated control system. The most common of these systems is the electro-pneumatic control system.

More than 70 percent of all existing air compressors utilise electro-pneumatic control systems. These compressors feature electric and mechanically controlled devices -- such as pressure switches, solenoid valves and metering pins -- that adjust the loading and unloading through the use of an inlet throttle and/or a bypass valve. These control systems typically rely on mechanical pressure switches to monitor the compressor's discharge pressure. In addition, electro-pneumatic systems typically feature a series of mechanical trip switches that discontinue compressor operation when pressures or temperatures reach critical levels.

The most advanced control system available today is an electronic or microprocessor-based control system. Instead of common pressure and metering devices, the microprocessor control system relies on electrical transducers and sensors. These devices sense air pressure and temperature values, which are then transmitted to a central microprocessor. The microprocessor interprets the information and adjusts the compressor's output through an integrated control system. The microprocessor also measures and stores operating data for future maintenance needs.

Even though microprocessor systems have been available only since the late 1980s, they are quickly gaining popularity. In fact, most compressor manufacturers offer at least one design that is microprocessor based and some have completely eliminated other older, less efficient control systems on new units. In fact, some manufacturers offer microprocessor control systems as compressor accessory units, such as air dryers and conversion kits that can be fitted to older compressors. Such upgrades add significant benefits and reduce maintenance reduction, especially on reciprocating compressors.

Microprocessor systems offer significant advantages over electro-pneumatic controls. Here are some examples:

3.21 Measurement Accuracy

Measurement accuracy is one of the critical functions of a control system. The risk of compressor damage and downtime increases as measurement accuracy decreases. If a temperature alarm setting rises over time, the compressor runs the risk of operating at a level that may cause damage. Temperature and pressure switches on the electro-pneumatic systems have been known to drift and change set points with time and wear. Microprocessor control systems, however, can provide an exact value. Settings will not slide or drift once set, reducing the risk of compressor damage.

Inaccurate measurements also adversely affect the control systems' ability to perform in extreme environments. Changes in ambient conditions, over time, required pressure and temperature gauges to be re-calibrated to maintain accuracy. This can be a time-consuming and costly activity that requires skilled instrument technicians. Microprocessor system transducers are less subject to conditions, such as vibration and heat. Re-calibration, if required, is accomplished by a simple push button method from the microprocessor control panel. Therefore, overall downtime is minimised.

3.22 Ease of Maintenance

Many companies typically perform routine maintenance programme for compressors that require daily readings of temperatures, pressures, and functions recorded in sequential log sheets.

With most control systems, operators are required to manually record all gauge readings from the compressor. On many compressors with electro-pneumatic

systems, gauges monitor several functions on the compressor and are sometimes unlabeled and occasionally require operators to gather multiple readings to ascertain compressor functions. By incorporating all controls on one microprocessor panel, operators can obtain actual operating values from one central location at the touch of a button.

For instance, monitoring the air end discharge temperature of rotary screw compressors can be a critical element in reducing downtime. In this case, the microprocessor control system can alert operators to any changes in these values to allow for preventive maintenance. Further, the addition of the microprocessor controls to older centrifugal and reciprocating units usually eliminates a variety of complicated capacity control devices.

The microprocessor panel also allows operators to adjust shutdown set points automatically and respond to alerts. The task of mechanically resetting each protective switch is no longer necessary. The microprocessor allows resetting from the control panel.

When compressor units shutdown, it is sometimes difficult to pinpoint the cause because several alarms may have been activated. But microprocessor control systems can monitor multiple alarms, and if shutdown occurs, recall the alarms to help identify the various problems.

Also, the microprocessor control system help troubleshooting through its monitoring alarm system. Even if a warning alarm is activated when the compressor is unattended and the system corrects itself, the alarm will remain on the microprocessor panel along with various operating parameters that were present at the moment of the alarm. This enables operators to reconstruct and evaluate the conditions when the warning alarm was activated.

3.23 Remote Access and Multiple Compressor Sequencing

Two additional benefits of a microprocessor-based system are based on its ability to program functions for remote activity, either for communications between operator and compressor unit or between two compressor units.

One of the features available on some of today's microprocessors is the ability to incorporate remote or two-way communications with the microprocessor unit. By adding a two-way communications link with the control system, operators can integrate plant-wide control systems and communicate operating functions to a

remote data terminal or computer.

Data links also enable operators to monitor system performance as well as program compressors to load, unload and alter sequencing from a remote site.

Another advantage of two-way communications is the ability to retrieve maintenance observations and statistical data to develop operating trends that will enable plant operators to relegate "unscheduled" system outages as part of the routine maintenance program.

Compressor control systems also allow operators to program units to automatically control and manage the functions of many compressors through one system control. Frequently called system controllers, these units can adjust to air demand fluctuations and maximise operating efficiencies while reducing excessive energy consumption.

System controllers tend to utilise a single pressure transducer, installed at an appropriate point in the compressed air system, to monitor system-wide pressure and to implement operating adjustments as programmed. Compared to typical sequencers, which require an overlapping or cascade style system pressure band and a fixed rotation, the controllers can operate several compressors on a common control pressure band to maximise energy conservation.

In addition, system controllers can be programmed for a number of operating parameters, including target system pressure, system pressure band, compressor load and unload delay times, sequential control mode, and start and stop sequencing.

As technological advances continue, microprocessor control systems will move beyond basic regulation of compressor functions to offer operators an unbounded selection of integrated functions that will not only extend the life of the compressors, but further increase efficiencies in overall plant operations.

Section 4 - Case Studies

A number of case studies have been briefly dealt with here. It must be mentioned however, that all investment and related payback periods are as per the existing tariffs and economic conditions prevailing at the time of the audit. These are undoubtedly subject to change in current circumstances.

4.1 Using Blower Air instead of Compressed Air for Coal Conveying to Storage Bin in Atox Mill Section

In a cement plant in Maharashtra producing 2.5 million tonnes of cement, annually, the detailed energy audit in 1997 examined replacement of compressed air by blower air for conveying coal to the storage bin in the atox mill section.

The reciprocating air compressor was used to supply the required at Claudius Peters Pump for coal conveying to the storage bin at 0.8 kg/cm^2. For a low pressure application such as this, the audit recommended using blowers in view of their lower specific power consumption compared to air compressors.

Existing System:

Air flow rate required		= 965 m^3/h
No. of compressors supplying air		= 2
Power consumption by compressors:		
	K2U07	= 27.6 kW
	K2U11	= 35.4 kW
Total power consumption		= 63.0 kW

Audit Recommendation:

Installation of a blower to supply coal-conveying air

Capacity of blower required	= 965 m^3/h
Blower air pressure	= 1 kg/cm^2
Blower power consumption	= 50 kW

Savings Envisaged:

Power savings	= 13 kW

Annual energy savings @ 18 hr/day	
And 330 days per year	= 77220 kWh
Annual Cost savings @ Rs.3/kWh#	= Rs.231660 /-
Investment for Blower	= Rs.1,18,800 /-
Investment for 75 HP 1440 rpm Motor	= Rs.75,000 /-
Total investment required	= Rs.1,93,800/-
Simple payback period	= 11 months

4.2 Installation of Single Large centrifugal Compressor

In a cast-wheel manufacturing plant, situated in southern India, there are six non-lubricated single-stage reciprocating compressors, one screw compressor and one diesel set driven compressor. All compressors are located centrally. During normal operation, only the reciprocating and screw compressors are in operation. The diesel set driven compressor is in operation only during peak load.

Compressed air is mainly used for pressure pouring, instrument and valve control, pneumatic conveying, lifting and tilting and electrode cooling.

Total compressed air generation	= 7107.76 m^3/h
Compressed air leakage	= 3796.97 m^3/h
Compressed air requirement	
after arresting 75% of leaks	= 4260.03 m^3/h
Specific energy consumption	= 8.7 kW/ (100 m^3/h)
Corresponding power consumption	= 391.48 kW

Audit Recommendation : The detailed energy audit in 1996 recommended installation of a reciprocating compressor:

Air requirement	= 4500 m^3/h
Compressed air pressure required	= 6.5 kg/cm^2g
Specific energy consumption	= 8.00 kW/(100m^3/h)
Corresponding power consumption	= 360 kW
Saving in power	= 31 kW
Savings in power	= 31 kW
Energy savings	= 223200 kWh

All energy tariffs mentioned are as prevailing at the time of the audit. With subsequent hikes in tariffs, it is evident that the investment will become all the more viable and attractive.

Cost savings @ Rs. 3.50/kWh#	= Rs. 781200
Savings in maintenance	= Rs. 200000
Total savings	= Rs. 981200
Investment required for two compressors Using one as standby	= Rs. 4000000
Simple payback period	= 4.0 years

4.3 Replacing Single Stage Compressor with Two Stage Compressor

In a cement plant in Maharashtra producing 2.5 million tonnes of cement, annually, the detailed energy audit in 1997 examined replacing the single stage compressor with a two stage one.

Power savings	= 16.37 kW
At current operating levels and loading time, 70% of the savings were feasible	= 16.37 x 0.7
	= 11.46 kW
Annual energy savings @ 3000 hrs/annum	= 0.34 lakh kWh
Cost of Energy Savings @ 4.65/kWh#	= Rs. 1.60 lakh
Cost of implementation	= Rs. 3.00 lakh
Simple payback period	= 1.9 years.

4.4 Replacement of Existing V Belts with Synthetic Flat Belts

In a cast-wheel manufacturing plant, situated in southern India, there are six non-lubricated single-stage reciprocating compressors, one screw compressor and one diesel set driven compressor. All compressors are located centrally. During normal operation, only the reciprocating and screw compressors are in operation. The diesel set driven compressor is in operation only during peak load.

Compressed air is mainly used for pressure pouring, instrument and valve control, pneumatic conveying, lifting and tilting and electrode cooling.

All compressors except two, are driven by V-belts V-belts consume more power when compared with synthetic flat belts. The latter consume 3 to 6% less power

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All energy tariffs mentioned are as prevailing at the time of the audit. With subsequent hikes in tariffs, it is evident that the investment will become all the more viable and attractive.

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than V-belts. The possible energy savings by conversion to flat belts is given below:

Actual kW	Operating Hours/year	Annual on-load hours	Power Savings kWh/year	Cost Savings, Rs/year	Investment Rs/year	Payback Period, Month
75.2	4000	3200	9626	33690	25000	9
71.3	4000	3200	9126	31942	25000	9
73.6	4000	3200	9421	32973	25000	9
75.3	4000	3200	9638	33734	25000	9
64.8	4000	3200	8294	29030	25000	10
75.5	4000	3200	9664	33824	25000	9
					150000	9

Cost of investment includes cost of flat belt, cost of new pulleys etc

Energy savings	= 55770 kWh/year
Cost savings	= Rs. 195190 per year
Investment period	= Rs. 150000
Payback period	= 9 months

4.5 Use of Variable Speed Drive to operate Compressor

In a sophisticated automotive component manufacturing plant located in South India, there were seven screw-type air compressors, driven by 132 kW squirrel cage induction motors. Normally, five compressors continuously feed 750 cfm each at 7 kg/cm^2 for base load requirements, while the sixth takes care of load fluctuations and the seventh remains a standby.

A detailed energy audit of the compressors revealed that for one of the compressors, the unloading time was 40%, with the rest being loading time. The associated power readings are given below.

Mode of Operation	Voltage	Current	p.f.	Load (kW)
No load	413	93.3	0.47	30.0
Unloading	413	205	0.71	121.4

In order to conserve energy in the presence of fluctuations in load, it is desirable to install a variable speed drive (VSD) for this compressor.

Full load power	= 121.4 kW
No-load power	= 30 kW
Average energy consumption/hour	= 84 - 88 kWh
Percentage load (36 minutes)	= 60%
Percentage unload (24 minutes)	= 40%
Present free air delivery during loading	= 1159 Nm^3/h
Speed	= 1500 rpm

Calculations

Requirement of free air after installing VSD	= 1159 x 0.6 + 0 x 0.4
	= 695 Nm^3/h
Current energy consumption	= (121 x 0.6 + 30 x 0.4)
	= 85 kW

The compressor speed could be reduced by as much as 60%, depending upon the average loading of 60% of the time. With the installation of the VSD, the speed reduction would ensure that the average air delivery requirements are complied with.

Speed of operation after installing VSD	= 900 rpm
Theoretical power required for Compression of 1159 Nm^3/h at $7 kg/cm^2$	= 72 kW
System efficiency	$= \frac{72}{121.4}$
	= 0.58
Theoretical power required for Compression of 659 Nm^3/h at $7 kg/cm^2$	= 43 kW
Actual power required	$= \frac{43}{0.58}$
	= 74.1 kW
Allowing 2% drop in system efficiency, Actual power required	= 75.6 kW
Present power consumption	= 85 kW
Saving in power	= 9.4 kW
Annual energy saving for 8000 hours	= 75200 kWh
Value of saving @ Rs. 4/kWh	= Rs. 3 lakh
Investment required	= Rs. 9 lakh
Simple payback period	= 3 years

4.6 Energy Savings by Drawing Fresh Cold Ambient Air

In a public sector unit in Bangalore, it was found from the detailed energy audit in 1994 that compressor room temperature was 8°C higher than the ambient air temperature. For every 4°C rise in inlet air temperature there is 1% increase in energy requirement.

Data

Ambient air temperature	= 32°C
Compressor inlet air temperature	= 40°C
Temperature difference	= 8°C

Calculations

Total energy saving	= 1/4 x 8 = 2%
Average monthly electricity consumption for compressors	= 55,000 units
Power for running under unload conditions	= 11,000 units
Energy saved per month	= 44,000 x 2/100
	= 880 units
Energy saved per annum	= 10,560 units
Cost savings @ Rs. 2.00# per unit	= Rs. 21,000
Cost of implementation	= Rs. 50,000
Pay back period	= 2.4 years

4.7 Energy Savings through Reduced Pressure Settings

A detailed energy audit was conducted in 1997 for a cement plant in Maharashtra producing 2.5 million tonnes of cement, annually.

Findings :

The audit on air utilisation revealed that the air pressure required at the end-use points was less than 2.75 kg/cm^{2}g.

All energy tariffs mentioned are as prevailing at the time of the audit. With subsequent hikes in tariffs, it is evident that the investment will become all the more viable and attractive.

Data:

Particulars	Compressor 1	Compressor 2
Type	Portable	Portable
Rating, kW	7.5	3.75
Capacity, m^3/h	30	28.5
Operating pressure, kg/cm^2g	7	7
Pressure settings, kg cm^2g	7-5	7-5
Operating h/year	8640	8640
kWh consumption/y	43200	12960
Cost of electricity, Rs/kWh#	4.00	4.00

A recommendation to reduce the pressure settings from 7-5 kg/cm^2g to 4 - 3 kg/cm^2 g could effect annual savings of Rs. 27,000 in the energy bill with marginal investment and immediate payback.

4.8 Checking Free Air Delivery (FAD) of Compressor

In a cement plant in Maharashtra producing one million tonnes of cement clinker, annually, the detailed energy audit recommended assessing the output of the compressor. The FAD test by suction method was carried out. The FAD is calculated by the pump-up method.

The audit revealed that there were a few compressors whose FAD was rather low. Increasing the FAD by overhauling the compressors could achieve significant savings in energy consumption, as shown below.

Compressor	Present FAD (cfm)	Deviation for 75% rated FAD (cfm)	Savings in kW	Running hours per year	Saving in kWh per year
Packing Plant					
Compressor # 1	220	42.5	9.4	8000	75200
Compressor # 2	215	47.5	10.8	3000	32400
Compressor # 3	306	84.0	22.0	6120	134640
Central Plant					
Compressor # 1	369	21.0	5.1	8000	40800

All energy tariffs mentioned are as prevailing at the time of the audit. With subsequent hikes in tariffs, it is evident that the investment will become all the more viable and attractive.

Total energy savings annually	= 2.83 lakh units
Value of annual savings @ Rs. 2.40/kWh	= Rs. 6.79 lakh
Investment for overhauling compressors	= Rs. 2 lakh
Simple payback period	= About four months

4.9 Cleaning of Fouled Inter - Coolers

In a detailed energy audit of a leading public sector unit in Bangalore in 1994, it was observed that the interstage cooler outlet air temperature was high, indicating that the tube insider the intercooler is fouled. Such hot air entry into the second stage will reduce the efficiency of the compressor.

Compressor capacity	= 15.15 m^3/min
First stage outlet air pressure	= 1.5 lg/cm^2
First stage outlet air temperature	= 73°C
Second stage outlet air pressure	= 5.5 kg/cm^2 (80 psi)
Second stage outlet air temperature	= 40°C
15.5 m^3 of air at 1.5 kg/cm^2 pressure and 40°C occupies	= 10.43 m^3
15.15 m^3 of air at 1.5 kg/cm^2 pressure and 73°C occupies	= 11.52 m^3
Reduction in volume	= 1.03 m^3
Power required to compress this volume to 5.5 kg/cm^2 =	= 4.5 kWh or 54 units/day

An audit recommendation to clean the fouled inter-cooler and after-cooler tubes periodically could effect annual savings of Rs. 50,000 with no investment.

4.10 Replacement of Existing Refrigerated Dryer with Heat of Compression Dryer

In a cast-wheel manufacturing plant, situated in southern India, there are six non-lubricated single-stage reciprocating compressors, one screw compressor and one diesel set driven compressor. All compressors are located centrally. During normal operation, only the reciprocating and screw compressors are in operation. The diesel set driven compressor is in operation only during peak load.

Compressed air is mainly used for pressure pouring, instrument and valve control, pneumatic conveying, lifting and tilting and electrode cooling.

The plant has three refrigerated dryers. For drying air, compressed air from the compressor is passed through chillers of the dryers to condense and drain the water vapour in the air. The vapour dew point of these dryers is 2°C. Due to the high dew point of the dryer, the removal of water is efficient and vapours are carried with compressed air to the end points. The total electricity consumption in all three dryers was estimated at 97200 kWh per year.

Present system:

Type of dryer = Refrigerated
Make of dryer = Sabro
Dryer capacity = 1000 cfm
= 1690 m^3/h
Dryer motor rating = 4.5 kW
Dew point = 2° C
Power consumption:

Dryer	Power	Operating hours	Energy kWh/year
1	4.5	7200	32400
2	4.5	7200	32400
3	4.5	7200	32400
Total			97200

Total energy consumption = 97200 kWh/year
Annual cost of energy = 340200 Rs/ year

Proposed System:

It was suggested to replace the refrigerated type of dryer with heat of compression dryer, wherein heat in compressed air is utilised to generate the desiccant. This could avoid the dryer compressor and the cooling water to the dryer, while catering to a very high water removal rate.

Savings in energy = 97200 kWh/year
Cost savings = Rs. 3.40 lakh/year
Investment required = Rs. 14.00 lakh
Payback period = 4.12 years

This measure was estimated to save annually Rs.0.3 million in energy bills, with a cost of implementation of Rs. 1.5 million to payback in about four years.

4.11 Converting Electrical Heated System of Air Dryer to Steam Heated System

A detailed energy audit was conducted in 1998 at a leading aluminium refinery in India. The plant has four K.G.Khosla make non-lubricated reciprocating compressors of capacity 72.88 m^3/min each located at centralised compressor house. During normal operation hours all four compressors are in operation.

The present system is an externally heated adsorption type air drying system, which uses electrical heating for regeneration of the activated-alumina bed. It was recommended that Instead of using electricity for heating the regeneration air, steam readily available in the plant could be used, by retrofitting the electrical heaters with steam heated systems.

The 9 ata steam available near the calcination plant could be piped to serve the steam requirement of the air dryers. The condensate could be let into the collection tanks available in the evaporator section, from where it could be pumped to steam generation plant.

Capacity of the air dryers - 63 & 64	= 2100 Nm^3/h (each)
Capacity of the air dryer - 65	= 900 Nm^3/h
Cycle time	= 8 h
Heating period	= 6 h
Cooling period	= 2 h
Total power consumption	= 152 kW
Energy consumption per day	= 6 h/cyl x 3 cyl/day x 152 kW
	= 2736 kWh
Enthalpy of steam at 9 ata.	= 662 kcal/kg
Latent heat of steam at 9 ata.	= 485 kcal/kg
Total heat required to be transferred to the air (i.e. heat equivalent of 2736 kWh)	= 2736 kWhx 860 kCal/kWh
	= 2352960 kcal
Assuming effectiveness of heat exchanger to be 85 %,	
Amount of steam required for heating regeneration air	= 2352960/(485 x 0.85)
	= 5708 kg/h

Cost of electricity	= 1.00 Rs/kWh
Assuming steam cost for 9 ata steam as Rs. 60 per ton of steam,	
Cost savings per day	= Cost of electrical energy saved - Cost of steam
	= Rs. 2394 /day
Annual operating days	= 350 days

Assume 80% of the saving calculated is achievable after considering pumping cost, etc.

Annual cost savings	= Rs. 6.70 lakh
Investment required	= Rs. 15.0 lakh
Simple payback period	= 2.2 years

In this particular instance, the cost of electricity is Rs. 1.00/kWh, on account of power being wheeled. However, it is evident that the investment would be even more attractive with current power tariffs for bought-out power.

4.12 Decentralisation of Compressed Air System

A foundry in Southern India produces various kinds of cast wheels. The plant has 8 compressors, of capacities ranging from 16.08 to 28.32 m^3/min. The industry uses a unique operation called pressure pouring, wherein molten metal is pushed into the mould at a high pressure, using compressed air.

Pressure pouring is a critical operation and any disturbances in the compressed air system affect the pouring process. The pressure required for pouring was 1.5-2.8 kg/cm^2g, whereas the compressed air was supplied at 6 - 6.5 kg/cm^2g. Pressure reduction was achieved by a regulatory valve. To avoid the pressure disturbances in the compressed air main system and to achieve energy savings it was recommended in 1996 to isolate pressure pouring operation from the rest of the compressed air network and dedicate separate compressors for generating compressed air at low pressure (3.5 kg/cm^2g).

<u>Data</u>

Compressed air supply pressure	= 5.5-6.5 kg/cm^2g
Pressure required for pouring	= 20 -40 psig
	= 1.5 - 2.8 kg/cm^2g
Casting rate	= 28 wheels / 40 min
	= 42 wheel /h
	= 86 sec / wheel

Internal volume of pouring pot with lid	= 9.69 m^3
Volume of empty ladle	= 2 m^3
Effective volume of system with empty ladle	= 7.69 m^3
Effective volume of system with full ladle	= 3.7 m^3
Average effective volume of the system	= 5.695 m^3
Average pressure required for pouring	= 1.8 kg/cm^2 g

<u>At Average Conditions=</u>

Free air required for pouring operation	= 15.946 m^3
Compressed air required per hour	= 669.732 m^3/h

<u>At ladle empty conditions</u>

Free air required for pouring operation	= 21.532 m^3
Compressed air required per hour	= 904.344 m^3/h

<u>At ladle full conditions</u>

Free air required for pouring operation	= 21.532 m^3
Compressed air required per hour	= 435.12 m^3/h

Compressed air requirement	= 669.732 m^3/h
	= 670 m^3/h
Allowance factor	= 25%
Total power consumption	= 72.86 kW

<u>Proposal:</u>

Dedicating one/two reciprocating for pressure pouring and generating air at 3.5 kg/cm^2

Theoretical power consumption	= 39 kW
Efficiency of compressor	= 65%
Proposed power consumption	= 60 kW
Savings in power	= 12.86 kW
Annual power savings	= 92586 kWh
Annual cost savings	= Rs. 324050

Investment:

a. Receiver capacity required

Minimum capacity of receiver	= 15.5 m^3
Present capacity of receivers	
- At compressors (2 receivers of 2m^3 each)	= 4m^3
- At pouring station	= 4m^3
- Total capacity	= 8m^3
Additional receiver capacity required	= 8m^3
Cost of receivers (2 no of 4m^3)	= Rs. 350000

b. Piping cost

Length of pipe required	= 300 mts
Pipe diameter	= 5 inches
Cost of piping	= Rs. 100000
Total investment required	= Rs. 450000
Payback period	= 1.4 years

4.13 Arresting Compressed Air Leakage

Present Status:

In a leading public sector unit in Bangalore, a detailed energy audit was conducted in 1994. The no-load test was carried out to quantify the leakage level. During the test it was ensured that no equipment/maintenance personnel is using compressed air. Four compressors were operated to observe the loading and unloading of compressors. Leak survey was conducted to identify major leaks.

It was observed that these five compressors were on load continuously without unloading. Time Vs. Pressure in the main header was monitored to assess the pressure raise/fall. It was observed that the pressure in the header was stabilised to 4.6 kg/cm^{2}g after 15 minutes. This indicates all five compressors were operating continuously to compensate the leakage.

Time Vs Pressure

Time, hours	Main header Pressure, kg/cm^2 g
12:26	5.0
12:27	4.9
12:28	4.8
12:29	4.8
12:30	4.7
12:31	4.6
12:32	4.6
12:33	4.6
12:34	4.6
12:35	4.5
12:36	4.5
12:37	4.5
12:38	4.5
12:39	4.5
12:40	4.6
12:41	4.6
12:42	4.6
12:43	4.6
12:44	4.6
12:45	4.6
12:46	4.6

Quantum of Compressed air leakage

Actual FAD, m^3	Actual kW
779.4	73.6
768.9	75.3
686.1	64.8
924.8	75.5
637.8	60.1
3797.0	349.3

Total quantity of compressed air leakage	= 3797.0 m^3/h
Power consumption of compressors	= 349.3 kW
Total compressed air generation	= 7107.76 m^3/h
Leakage level	= 53%

Proposal:

The compressed air leakage level in the system was 53% of total generation. The acceptable leakage level should not be more than 15% of total air generation. Compressed air leakage could be brought down to the acceptable level by simple measures such as replacing/ rectifying the valves, joints, fittings, hoses etc., leak surveys and no-load tests should be conducted periodically in order to keep leakage level in limits.

Power savings by arresting 85% of leaks	= 297 kW
Feasible savings considering no-load power	= 80%
Achievable power savings	= 238 kW
Annual operating hours	= 7200 hours
Annual energy savings	= 1710271 kWh
Cost of energy	= Rs. 3.5 per kWh
Annual cost savings	= Rs. 59.86 lakh
Investment requirement	= Rs. 5.00 lakh
Simple payback period	= 1 month

4.14 An Intelligent Control System For Balancing Compressed Air System

Industrial multi-compressor systems typically feature individual controls, mainly 1 to 4 pressure switches that can be set to certain values. Depending on the discharge pressure level, a compressor runs either loaded or unloaded.

To guarantee the supply of compressed air in changing production situations the pressure of compressed air systems is kept higher than the actual air demand of processes and machinery, which they provide. This, however, means energy losses. To eliminate these disadvantages a Finnish company, Sarlin-Hydor Oy, has developed an intelligent control system that floats the pressure setting according to air demand and avoids pressure fluctuations.

The Sarlin balance control system is based on an exclusive software algorithm. The control unit monitors both the network pressure and the discharge pressures of the compressors. The software maintains the pressure at an adequate level

utilising the lowest possible compressor capacity. The pressure level required and the deviation allowed are set at the interface. Running sequences can also be set to equalise compressor run times.

4.15 Case study

One of the first Sarlin Balance systems was installed at a board machine No 5 of Enso Oy Tainiokoski mill in Imatra, Finland. The compressed air system includes six compressors of 250 kW. The average consumption of compressed air is 110 cubic meters/minute.

Before installation the average pressure level was 6.86 bar and the energy consumption was 6800 MWh/year. After installation, the pressure was reduced to 6.41 bar and the total energy consumption by 599 MWh/year or 8.8%.

The fluctuation of pressure level was about 0.3 bar, which means smoother production and higher product quality.

Technical Data

The Sarlin Balance system can be used up to eight compressors. The number of Balance modules, which will be installed, and thus the number of compressors is unlimited. The menu is based on 2 x 6 digits with 6 selection keys. It has an RS-connection and MODBUS communication protocol. Pressure sensors are 2 x 10 (16) bar pressure transmitters (4-20 mA).

Ambient temperature can be 5 - 45°C. Dimensions are 224 x 190 x 79 mm. Remote control connection is optional. The balance system is easy to install for different types on compressors.

4.16 Variable Speed Drive for an Air Compressor

Case study

The company "Glasuld" produces insulation products in glass wool. In recent years, the company has made many improvements in its use of compressed air. From 1986 to 1992, the specific power consumption for compressed air was reduced by 50%. In 1992, the electricity consumption for compressed air amounted to 6 million kWh or about 10% of the total electricity consumption of the factory. However, Glasuld wanted to reduce the energy consumption further

and in 1993 a Variable Speed Drive (VSD) was fitted to the main compressor. This resulted in a 29% reduction of the electricity consumption.

At Glasuld compressed air is used in control valves, for pneumatic tools, for cleaning filter bags and as supplementary air for the 2.8 bar and 1.3 bar air systems.

Compressed air is supplied by a new Atlas Copco GA 132 compressor with an output of 22.8 m^3/min and an older spare compressor. A diesel powered back-up compressor can maintain the compressed air supply for essential parts of the production process.

The new compressor is designed to supply the highest air consumption demands of production and still be able to deliver some supplementary air.

The GA 132 compressor is an oil-flooded screw compressor, which is simply controlled by on/off, switches. Loaded power input is about 138 kW and average off-loaded power of about 65 kW. It takes considerable time to decrease power to the off-level. Due to this some of the electricity consumption is used to drive the compressor without air production. For Glasuld it was estimated to be 260 MWh in 1992 corresponding to 29% of the electricity consumption of the compressor.

Technical Data

If the duration of the off-period can be increased, the mean power would be reduced. Therefore, Glasuld considered speed control of the compressor and decided to install a variable speed drive to the main compressor. This resulted in saving of 200 MWh/year. A SAMI frequency converter from ABB was chosen. The converter is directly connected to the motor.

The rotational speed can be varied from 40 to 100% of the nominal rotational speed, which covers the required range. The compressor drives on/off at 20 Hz when the demand for air is below 40% of the output of the compressor. The control takes place with a PI regulator, which keeps a mean pressure at 6.9 bar. Fast regulation uses larger speed increments to avoid starting the reserve compressor. It takes 15 seconds totally to increase from 20 to 50 Hz.

Energy Data

The installation of the frequency converter cut the total electricity consumption

from 832 MWh/year to 632 MWh/year giving a total saving of 200 MWh/year.

The frequency control seems to be most interesting for compressors driving 40-80% load most of the time.

The entire electricity consumption in off-load was expected to be saved, but because of losses in the frequency converter etc. this was reduced to a net saving of 200 MWh/year corresponding to DKK 60,000/year (approximately USD 10,000/year).

The investment of the project was DKK 180,000 at a payback of three years.

4.17 Control Systems for Compressor Air Usage : Boeing Commercial Airplane Group

Like many industrial manufacturers, Boeing Commercial Airplane Group uses a lot of compressed air. But, as an audit of their plant revealed, they were making too much available too much of the time - and wearing out their equipment too fast. The solution? A new control system that shuts down compressors, thereby prolonging equipment life and cutting annual energy costs by $92,000. BEST acknowledged this energy efficiency with a Business Award.

Boeing knew that it needed to change something at its three-building campus in Northeast Portland. To produce control columns, aisle stand assemblies and other plane parts, the company ran eight air compressors, most only at part load Then in 1993 PGE's industrial account manager to Boeing offered to help them identify and fund significant energy efficiency upgrades. The two companies got creative.

Through PGE's Process Efficiency Improvements Program, Boeing hired an engineering firm to find the big energy users and losers. They focused on Boeing's eight air compressors. They had five two-stage screw compressors and three two-stage cylinder reciprocating compressors with a total capacity of 12,000 cfm of air at 115 psig.

Each building had one or more cooling towers, and all compressors had load/unload controls and hour meters to record run times. Quickly, the consultants found their prime target: energy and air wasted by running compressors at part-load.

The solution was to link compressors in the three buildings, so that at most two

would have to run at all times. The means was a 1,200-foot-long eight-inch diameter air line buried in a precast concrete trench that connected all of their compressed air systems. The cost was $180,000 (Rs. 8.1 million), part of which was paid for by a $40,000 (Rs. 1.8 million) incentive from PGE.

Boeing now uses just five compressors. Two are base load carriers and run fully loaded; one is for emergency back-up.

Since the system went on-line in 1996, the company has halved annual compressed air system energy use, from 4.5 million kWh to just 2.2 million, thereby saving $92,000 (Rs. 4.1 million). The company also saves $9,500 (Rs. 427,000) in equipment depreciation and $8,500 (Rs. 382,000) on maintenance parts and labour each year. As additional benefits, they've lengthened equipment life expectancy and can deliver uniform air to all sites.

4.18 Compressed Air Costs Reduced by Automatic Control System

At Land Rover, located in Solihull, United Kingdom, a computerised compressor control system has been installed, which regulates generation pressure in response to a pressure transducer positioned at the end of the air distribution network. The system uses predictive switching to avoid idling losses to achieve lowest possible generation pressure at all times.

The average reduction in weekday use of electricity was 16.5 %. The installation costs of £ 31,700 could payback in just eight months.

4.19 Ultrasonic Detection of Compressed Air Leaks

Permissible limits for air leaks are often 5 – 10 % in industrial installations. At the Ford Stamping Plant in Geelong, Victoria, Australia, an ultrasonic inspection tool pinpoints the exact location of air leak. As any gas passes through a leak orifice, it generates a turbulent flow with detectable high frequency components. By scanning the test area with an ultrasound listening device, a leak can be heard or noted on the ballistic meter.

The potential savings are extremely high, with the cost of the instrument being Aus. $ 7,500 (Rs. 210,000) with a saving of about Aus. $ 2,000 (Rs. 56,000) per week.

4.20 Expanding an Existing Compressed Air Grid with Low Pressure Section

The Polarcup Company in Groenlo in The Netherlands produces paper cups, to be used for beverages and ice creams, in a manufacturing process including a sealing stage. The sealing machine uses heated air; furthermore, the products are transported through the manufacturing process by a pneumatic conveying system. Compressed air is drawn from 7 bar compressed air grid, fed by four compressors. Each compressor is equipped with an air cooler and a lyophilizer to dry the air, in order to prevent condensation in the pipes or in the machines. In the old situation, some 55 % of the total air consumption were used at a pressure of 3 bar, so high pressure air had to be choked, leading to an inefficient use of compression energy.

Section 5 – Checklists

In order to keep compression systems operating efficiently, various checks and inspections are recommended. These are summarised in the form of checklists.

1. Ensure air intake to compressor is not warm and humid by locating compressors in a well-ventilated area or by drawing cold air from outside. Every 4°C rise in air inlet temperature will increase power consumption by 1 percent.

2. Clean air-inlet filters regularly. Compressor efficiency will be reduced by 2 percent for every 25mbar-pressure drop across the filter.

3. Keep compressor valves in good condition by removing and inspecting once in every six months. Worn-out valves can reduce compressor efficiency by as much as 50 percent.

4. Install manometers across the filter and monitor the pressure drop as a guide to replacement of element. Keeps suction air velocity below 1400 m/min.

5. Minimise low-load compressor operation; if air demand is less than 50 percent of compressor capacity, consider change over to a smaller compressor.

6. Consideration to be given to regenerative air dryers which may use the heat of compression in their operation.

7. Fouled inter-coolers reduce compressor efficiency and cause more water condensation in air receivers and distribution lines resulting in increased corrosion. Periodic cleaning of inter-coolers must be ensured.

8. Compressor free air delivery test (FAD) must be done periodically to check the present operating capacity against its design capacity and corrective steps must be taken if required.

9. If more than one compressor is feeding to a common header, compressors must be operated in such a way that only one small compressor should handle the load variations whereas other compressors will operate more or less at full load.

10. The possibility of heat recovery from hot compressed air to generate hot air or water for process application must be economically analysed in case of large compressors.

11. Consideration should be given to two-stage or multistage compressor as it consumes less power for the same air output than a single stage compressor. Oversized compressors lead to power wastage.

12. If pressure requirements for processes are widely different (eg. 3 bar to 7 bar), it is advisable to have two separate compressed air systems. Reduce compressor delivery pressure wherever possible, to save energy.

13. Provide extra air receivers at points of high cyclic-air demand which permits operation without extra compressor capacity.

14. Retrofit modern speed regulation controllers in big compressors, say over 100 kW, to eliminate the `unloaded' running condition altogether.

15. Automatic electronic moisture drain trap timings must be optimised depending on the season to minimise wastage of compressed air along with condensed water.

16. Periodically adjust tension in drive belts. V belts can be retrofitted with flat belts for efficient operation and for 10% reduction in the power consumption.

17. If reservoirs fail to charge, check for air leakage in the by pass valves.

18. Use delay-timers to limit the number of compressor motors starting at the same time so as to reduce start-up loads, maximum demand and to increase the life of the compressor.

19. Check lubricating oil consumption from performance records and manufacturer's specifications. For three or four stage compressors, lube oil consumption of 0.11 kg.cm/1000 kWh is typical.

20. Read pH value of inter-cooler condensate. Look for indications of leakage from water side into tubes.

21. Inspect instrumentation frequently to ensure that operating oil pressure and temperature agree with manufacturer's specifications.

22. In centrifugal / axial compressors, monitor vibration of each impeller, in mills amplitude at a central control panel or scanning console; excessive vibration suggests misalignment, foundation settlement, debris in impeller rotors, out-of-

balance rotors, worn bearings, bent shafting or damaged drive coupling.

23. Check air compressor logs regularly for abnormal readings, especially motor current cooling water flow and temperature, inter-stage and discharge pressures and temperatures and compressor load-cycle.

24. Check availability of system (availability is that time during the year that the compressed air system is ready for operation divided by the total hours in a year, expressed in percent) from this, it is possible to determine whether the plant maintenance procedure is good or not.

25. Conduct in-plant seminars on maintenance, stressing on reduction of air wastage and improvement of air equipment performance.

26. Compressed air leakage of 40-50 percent is not uncommon. This can be brought down to less than 5 percent. It requires location and repair of all leaks; most leaks occur at loose pipe fittings, valve packing, shut off valves, worn-out filters, quick couplers and unused air tools. Carry out no-load tests periodically to locate leakage points.

27. Check manual drain for proper drainage and to prevent condensate build up and check safety valves to prevent excessive pressure and wear.

28. Install solenoid cut-off valves in the air system so that air supply to a machine can be switched off when not in use.

29. Present energy prices justify liberal designs of pipeline sizes and layouts to reduce pressure drops. A smaller dedicated compressor can be installed at load point, located far off from the central compressor house, instead of supplying air through lengthy pipelines.

30. Keep nozzles in good condition. A sandblast nozzle worn-out from 8 mm to 10 mm diameter will use an additional 1.9 m^3/min compressed air.

31. If operated continuously, blow-off nozzle with 3mm orifice consumes about 0.70 m^3/min at 7 bar pressure.

32. All pneumatic equipment should be properly lubricated, which will reduce friction, prevent wear of seals and other rubber parts thus preventing energy wastage due to excessive air consumption or leakage.

1. Misuse of compressed air such as for body cleaning, agitation, general floor cleaning, and other similar applications must be discouraged in order to save compressed air and energy.

2. Pneumatic equipment should not be operated above the recommended operating pressure as this not only wastes energy but can also lead to excessive wear of equipment's components which leads to further energy wastage.

3. Pneumatic instrumentation can be replaced by electronic instrumentation. Pneumatic transport can be replaced by mechanical system as the former consumed about 8 times more energy. Highest possibility of energy savings is by reducing compressed air use.

4. Pneumatic tools such as drill and grinders consume about 20 times more energy than motor driven tools. Hence they have to be used efficiently. Wherever possible, they should be replaced with electrically operated tools.

5. Blow guns for cleaning dwarf or moisture must be operated at the lowest satisfactory pressure than at a higher pressure. For example, at 1.4 bar a blowgun uses one third of the air it would use at 6.2 bar.

Some retrofits and new technologies relevant to compressed air systems are discussed in Appendix 3. Appenaix 4 describes the tests for compressed air systems in detail. Appendix 5 includes an international methodology for the audit of compressed air systems.

Section 6 - Economic Analysis of Investments for Energy Conservation

When any conservation opportunities are to be implemented, most measures do not require investments. However, it is possible that an investment, marginal or substantial, is sometimes incurred for specific energy saving opportunities. And, transferring the implementation from paper to actual practice involves making a decision - to invest or not to invest.

Usually, decisions are made regarding alternative solutions for utilisation of capital. At the outset, the decisions must not conflict with the objectives of the enterprise. These objectives can be constrained by social considerations or governmental regulations. They can be influenced partially by the owner's tastes or time required for implementation. However, the prime objective does not deviate from profit maximisation.

In order to aid the decision-makers, there are certain economic methodologies, which are followed. These are briefly discussed, although progressing beyond basic concepts would be beyond the scope of this manual.

All these methods are more or less reliable, depending on the accuracy of evaluation of the cash inflow and outflow, estimation of the discount rate (cost of capital) and prediction of the possible rate of increase of the energy price. Within these limitations, the most precise method is the Present Value Criterion, which compares the present value of all future after-tax cash inflow and outflow over a specified period of time to the present value of the cost of investment for the investment.

Although it may appear elementary, one has to recall here the fundamental rule of sunk costs, which says that in taking decisions about future investments, no role is played by past costs.

For example, when a new line of products is considered in a factory, the original book value of the existing old machinery already installed as irrelevant from the point of view of future cost evaluation. What is relevant is the present book value of the equipment, in the case that the old machinery can be sold or partially used to substitute the purchase of the new machinery. If the old machinery cannot be sold or used in the new production it is a "sunk cost" and has no relevance to the investment decision concerning the new machinery.

Present Value Criterion

The net present value (NPV) is defined as the difference between present worth of savings and cost of investment. The investment should be made if NPV is positive, and should be discarded if NPV is negative.

The present value method converts the money time series corresponding to the savings to an equivalent single amount at the date (year 0) when the decision to invest is to be taken. The present value criterion then compares this equivalent amount to the capital to be invested.

$$NPV = p \times \frac{1}{(1+r)^n}$$

Where p = future payments and income
r = pre-determined discount rate
n = number of years for which NPV is calculated

NPV indicates the return that the management can expect from the project at various discount rates. It can also be used to compare various projects with similar discount rates and risks, as well as compare them against a benchmark rate.

Internal Rate of Return (IRR) is the threshold rate at which the NPV is zero. It is the rate of return received for the project considering payments and income at regular intervals. This is commonly used for analysing investments in projects. A project is considered viable, if its IRR is greater than the interest rate offered by financial institutions for investing the capital with them that would be otherwise invested in the project.

Average Rate of Return Criterion

The average rate of return on investment criterion is not so precise as the present value criterion but it can provide a preliminary guide to investment decisions provided that the projected future annual cash savings can be assumed to remain constant.

For example, suppose the installation of a heat recovery device is considered. The heat recovery system installation costs Rs.10,00,000 and will last five years. The law permits a 20% annual linear depreciation factor. The new machine is expected to save Rs.3,00,000 in fuel costs annually.

Return on Investment (ROI)

The returns may be on the investment made or on a particular project or of the organisation as a whole.

Return on Investment (ROI) : Profit/Capital Employed

ROI is a combination of two ratios i.e., Profitability Ratio and Capital Turnover Ratio

Profitability ratio indicates the profitability of the organisation/investment/project while Capital Turnover Ratio indicates the efficiency with which the assets / investment are being employed. Greater the two ratios, higher will be the return on investment.

Generally the management analyses Profitability Ratios to take decisions pertaining to pricing policies, costs etc., while the Capital Turnover Ratio is analysed to take investment decisions.

The expected Return on Investment is generally the benchmark for investment decisions.

Pay-Back Period Criterion

The Pay-back Period Criterion evaluates the time required to recover an initial investment via an annual net cash flow. It is defined as the investment cost divided by the cash flow. In the previous example of the heat recovery systems, the pay-back time in years is equal to 3.3 years.

Similar to the return on investment method, the pay-back criterion does not take into consideration the discount rate, the change in energy prices, nor the lifetime of the investment project. It has one advantage over ROI in that a precise indication of the annual benefit, namely the cash flow, is used instead of profits. However, both suffer from the difficult in justifying the threshold value beyond which no project should be considered.

In practice, investment projects with a pay-back period of three years or less almost always have a positive net present value. Thus the pay-back period is

often used as a "filter", calculating NPV when the payback period is over three years and accepting the project when it is less.

Break-Even Parameters of Net Present Value

An important part of investment analysis, not to be confused with the pay-back period, is the calculation of the threshold value of a critical parameter of the net present value (NPV).

The threshold, or break-even value, is the value of a NPV parameter for NPV equal to zero. Any value beyond the break-even value will cause NPV to become positive and the investment acceptable.

Typical parameters studied in this manner include:

- The price of the service;
- The utilisation of the capacity of the investment;
- Various items of the cost of the project;
- The energy price increase, and
- Occasionally, the duration of the project.

When the latter is used as a parameter, the break-even time (in years) is a "true" pay-back period, where the discounted benefits begin to exceed the discounted costs.

Appendix 5 discusses the energy management approach and methodology in detail.

Appendices

Absorb
A method to trap liquids or gases by causing them to penetrate into the absorbent material.

Activated Alumina
An adsorption type desiccant.

Actual Capacity
Quantity of gas actually compressed and delivered to the discharge system at rated speed of the machine and under rated pressure conditions.

Adiabatic Compression
A type of compression where no heat is transferred to or from the gas during the compression process.

Adsorb
A method causing a liquid or gas to condense on the surface only of an adsorbing material.

Aftercooler
Heat exchangers for cooling air or gas discharge from compressors. Designed to reduce the temperature and liquefy condensate vapours. Both air cooled and water cooled units are available.

Air Actuator
An elastomeric bellow with specially designed metal end closures used in place of pneumatic or hydraulic cylinders. A device which induces action or motion with compressed air being the medium through which the power is transmitted.

Air Brush
A device for applying a fine spray by compressed air.

Air Bubble Technique
When compressed air is forced through a submerged perforated hose or pipe. Some applications include; ice prevention, reduction of salt intrusion, underwater basting, pneumatic breakwaters and general mixing and agitation

Aircooled Compressor
A compressor cooled by atmospheric air circulated around the cylinders or casing.

Air Cylinder
A component made up of a cylinder barrel, end covers, a piston rod, a steel or stainless steel piston. A device which induces action or motion with compressed air being the medium through which the power is transmitted.

Air Dryer
A device for drying compressed air by means of condensation obtained by over-compression or cooling, absorption, adsorption or a combination of the above methods.

Airflow
The motion of air relative to a body in it.

Air Leak
A crack or hole that accidentally admits a gas or lets it escape.

Air Nozzle
A projecting aperture at the end of a tube, pipe etc. serving as an outlet for compressed air. Reduces the demand on the compressor by generating the highest thrust and volume for the lowest possible air consumption.

Air Receiver
A receptacle which serves to store compressed air for heavy demands in excess of compressor capacity.

Amonton's Law
States that the pressure of a gas, at constant volume, varies directly with the absolute temperature.

Anti Pulsation Tank
Sometimes called a pulsation damper this is a small receiver fitted on the inlet or discharge of a reciprocating compressor. The device is designed to remove the resonance from the compressor thereby reducing noise.

Atmospheric Dew Point
Is the temperature at which water vapour begins to condense at atmospheric pressure. Is the same as dewpoint, but is related to atmospheric air only.

Axial Compressor
A compressor belonging to the group of dynamic compressors. Characterized by having its flow in the axial direction.

Barg
Bar gauge (similar to the acronym "psig")

Barometric Pressure
Is the absolute atmospheric pressure existing at any given point in the atmosphere. It is the weight of a unit column of gas directly above the point of measurement. It varies with altitude, moisture and weather conditions.

Blowdown
The difference in pressure between the opening pressure and reclose pressure of a valve. May be expressed in percentage of set pressure or "psig".

Blow-off Control
The compressor continuously compresses, however, when the maximum pressure is reached, the delivered air is blown off to the atmosphere instead of being fed to the receiver.

Brake Horsepower
The maximum rate at which an engine can do work as measured by the resistance of an applied brake. Expressed in horsepower.

Branch Lines
Are lines that supply equipment from sub headers

Breakdown Maintenance
Maintenance performed after a machine has failed to return it to an operating state.

Breaker
A hand held pneumatic tool. Designed for light demolition work, digging, making holes etc.

Breaking Pressure
Is that pressure of either the motive fluid or of the ejector gas discharge which causes an ejector to become unstable.

Charle's Law
States that the volume of a gas, at constant pressure, varies directly with the absolute temperature.

Clean Room
A facility or enclosure in which air content and other conditions (such as temperature, humidity, and pressure) are controlled and maintained at a specific level by special facilities and operating processes and by trained personnel.

Clean Pressure Drop
The pressure loss across the filter element determined under steady state flow conditions using a clean test fluid across a clean filter element.

Clearance
The maximum cylinder volume on a working side of the piston, minus the piston displacement volume per stroke. It is usually expressed as a percentage of the displace volume.

Cold Differential Test Procedure
Actual gage pressure on the test stand that includes correction factors for temperature, pulsation, vibration, constant back pressure, etc.

Cold Start
Starting a compressor from a state of total shutdown. Usually done with "local" control at the compressor. May be done with "remote" control, but only advised with "heavy" instrumentation and monitoring accessories.

Compressed
To reduce the volume of, by or as if by pressure.

Compressed Air
Air under pressure greater than that of the atmosphere.

Compressibility
A factor expressing the deviation of gas from the laws of hydraulics.

Compression Efficiency
Is the ratio of the theoretical work requirement to the actual work required to be performed on the gas for compression and delivery.

Compression Isothermal
Is a compression in which the temperature of a gas remains constant.

Compression Ratio
The ratio of the absolute discharge pressure to the absolute inlet pressure.

Compressor
A machine that compresses air, gases.

Condensate
A product of condensation.

Condenser
A device that changes a vapour into a liquid. Accomplished by exposing a tube containing vapour to air or by passing the tube through a water jacket.

Connector
The mating device that is inserted into the coupler of a quick coupler and locked to complete the connection. Also referred to as plug or nipple.

Constant Speed Control
The unit that runs continuously and matches air supply to demand, by loading and unloading the compressor.

Contaminant
Foreign matter carried in the air, gas or fluid to be filtered out. Includes air borne dirt, metallic particles produced by wear of moving parts of the air compressor, rust from metal pipelines.

Contaminant Capacity
The weight of a specified artificial contaminant that must be added to the influent to produce a given differential pressure across a filter at specified conditions. Used as an indication of relative service life.

Control Valve
A valve that controls the flow in air lines.

Coolant
Fluid cooling agent.

Cooling Tower
A cooling water supply system. There are two different types - Open and closed loop systems.

Critical Pressure
Is the saturation pressure at the critical temperature. It is the highest vapour pressure that the liquid can exert.

Critical Temperature
The highest temperature at which well-defined liquid and vapour states exist

Crosshead Compressor
A compressor belonging to the group of displacement reciprocating compressors.

Cycle
A single complete operation consisting of progressive phases starting and ending at the neutral position.

Cylinder
The piston chamber in a compressor or actuator.

Dead-end Pressure
Is the suction pressure attained by an ejector or positive displacement vacuum pump at zero capacity with the suction absolutely blanked off.

Degree of Saturation
Is the ratio of weight of vapour existing in a given space to the weight that would be present if the space were saturated at the space temperature.

Demand
Flow of air under specific conditions required at a particular point.

Demand Side Management (DSM)
The planning and implementation of strategies designed to encourage consumers to improve energy efficiency, reduce energy costs, change the time of usage, or promote the use of different energy source.

Desiccant
An adsorption type material used in compressed air dryers. Industry standards are activated alumina, silica gel and molecular sieves.

Design Pressure
The maximum continuous operating pressure as designed by the manufacturer.

Desorption
Opposite of absorption or adsorption. In filtration, it relates to the downstream release of particles previously retained by the filter.

Dew Point
Of a gas is the temperature at which the vapour in a space (at a given pressure) will start to condense (form dew). Dew point of a gas mixture is the temperature at which the highest boiling point constituent will start to condense.

Diaphragm
A stationary element between stages of a multistage centrifugal compressor. It may include guide vanes for directing the flowing medium to the impeller of the succeeding stage. in conjunction with an adjacent diaphragm, it forms the diffuser surrounding the impeller.

Diaphragm Compressor
Is a positive displacement reciprocating compressor using a flexible membrane or diaphragm in place of a piston.

Differential Pressure
The difference in pressure between any two points of a system or component.

Differential Pressure Indicator
an indicator which signals the difference in pressure between any two points of a system or a component.

Diffuser
A stationary passage surrounding an impeller, in which velocity pressure imparted to the flow medium by the impeller is converted into static pressure.

Directional Control Valve
A valve to control the flow of air in a certain direction.

Dirt Holding Capacity
The quantity of contaminant a filter element can trap and hold before the maximum allowable back pressure or delta P level is reached.

Discharge Piping
Is the piping between the compressor and the aftercooler, the aftercooler separator and the air receiver.

Discharge Pressure
Is the total gas pressure (static plus velocity) at the discharge port of the compressor. Velocity pressure is considered only with dynamic compressors.

Discharge Temperature
Is the temperature existing at the discharge port of the compressor.

Displacement Compressor
A machine where a static pressure rise is obtained by allowing successive volumes of gas to be aspirated into and exhausted out of a closed space by means of the displacement of a moving member.

Double Acting Compressor
A positive displacement type compressor.

Downstream
The portion of the flow stream which has already passed through the system or the portion of the system located after a filter or separator/filter.

Drag
Occurs when a valve does not close completely after popping and remains partly open until the pressure is further reduced.

Drain Valve
A device designed to remove surplus liquid from the compressed air system. Manual units range from petcock to a ball, gate or globe valve. Mechanical types consist of ball float. Electrical drains include solenoid type that is energized by a timer signal, or electric motor driven units. Also pneumatically activated drains.

Drive
A coupling between the compressor and the engine or motor. The three types of drives most common are; flange mounted motor, V belt drive or direct coupling.

Dry Bulb Temperature
Is the ambient gas temperature as indicated by a standard thermometer.

Dry Unit (Oil Free)
Is one in which there is no liquid injection and/or liquid circulation for evapourative cooling or sealing.

Dynamic Losses
Friction against duct walls, internal friction in the air mass and direction variations will cause a speed reduction and are therefore called dynamic losses.

Dynamic Type Compressors
Machines in which air or gas is compressed by the mechanical action of rotating vanes or impellers imparting velocity and pressure to the flowing medium. (Raise the pressure of the air by converting the energy from the velocity of the air to pressure.)

Duct
A pipe, tube or channel that conveys a substance (such as air throughout a building).

Efficiency
Ability of a filter to remove particle matter from an air stream. Measured by comparing concentrate of material upstream and downstream of the filter. Typical particulate sizes range from .3 micron to 50 micron.

Efficiency Mechanical
Is the ratio of the thermodynamic work requirement in the cylinder to actual brake horsepower requirement.

Efficiency Polytropic
Is the ratio of the polytropic compression energy transferred to the gas to the actual energy transferred to the gas.

Efficiency Volumetric
Is the ratio of actual capacity to piston displacement, stated as a percentage.

Ejector Compressor
A compressor belonging to the group of dynamic compressors.

Emulsibility
The ability of a non-water-soluble fluid to form an emulsion with water.

Entropy
Is a measure of the unavailability of energy in a substance.

FAD
Free air delivery. Air at the atmospheric conditions of the site and unaffected by the compressor. Flow is measured at the discharge valve of the compressor, after the aftercooler, the water separator and built in check valve. Capacity and power consumption are corrected to ISO 1217 standard reference conditions: Ambient temperature = °20C, Ambient pressure = 1 bar(a), Relative humidity = 0%, Cooling water/air = 20°C, Effective working pressure at discharge valve = 7 bar(a).

Filter
A device that removes solid contaminants, such as dirt or metal particles, from a liquid or gas (air is a gas), or that separates one liquid from another, or a liquid from a gas. The term filter describes the complete unit ... housing, filter element, internal by pass.

Filter Efficiency
The ability of a filter to remove specified test contaminants under specified test conditions from a specific test fluid, air, gas or liquid. Expressed as a percentage of the quantity of test contaminant introduced into the inlet of the filter test system

Flow Control Valve
A valve that controls the flow of air that passes through the valve. Used often for retardation or timing circuits, but especially for regulating the piston speed in cylinders.

Flow Diagram
A schematic flow sheet showing all controls involved with the system.

Flow Meter
An instrument for measuring the amount of air flow of a compressor. Measured in CFM.

Gas Laws
The behavior of perfect gases, or mixtures thereof, follows a set of laws. Boyle' law, Charle's law, Amonton's law, Dalton's law, Amagat's law, Avogadro's law, Poisson's law.

Gate Valve
A type of valve in which the closing element (the gate) is a disc that moves across the stream in a groove or slot for support against pressure. A gate valve has relatively large full ports and a straight line flow pattern. Very little pressure drop however subject to leakage if sealing surfaces are scored or marred or if debris becomes lodged in grove.

Gauge
An instrument for measuring, testing, or registering.

Gauge Pressure
Is pressure as determined by most instruments and gauges.

Guide
The portion of a valve used to guide the disc.

Guide Vane
A stationary element that may be adjustable and which directs the flow medium to the inlet of an impeller.

Head Adiabatic
The energy in foot pounds required to compress adiabatically and to deliver one pound of a given gas from one pressure level to another.

Header
The main distribution pipe.

Heat Exchanger
Is used to cool compressed air or gas. Designed to reduce the temperature and liquefy condensate vapours.

Heatless Dryer
Heatless reactivated dryer. By means of expanding cold dry air to near atmospheric pressure inside the regeneration tower, the dryer air picks up moisture from the saturated desiccant bed and is then purged to atmosphere.

Heat Reactivated Dryers
Are categorized as internal or external heat reactivated. Internal type - Process air enters the dryer through the inlet piping, is then dried as it passes through the desiccant bed, and discharges through the outlet piping as dry air. Regeneration of the desiccant is accomplished at atmospheric pressure, using steam or electric heaters, embedded in the desiccant bed. External type - Process air enters the dryer through the inlet piping, is then dried as it passes through the desiccant bed, and discharges through the outlet piping as dry air. Reactivation is accomplished using a reactivation blower or a cooler.

Heat Recovery
Recovering and utilizing the heat content of the compressed air.

High Efficiency Filtration
The unofficial filtration industry description for filters designed to trap small size contaminants.

Horsepower Indicated
The horsepower calculated from compressor-indicator diagrams. Applied only to displacement type compressors.

Horsepower Theoretical
The horsepower required to compress adiabatically the air or gas delivered by the compressor through the specified range of pressures.

Humidity Specific
The weight of water vapour in the air vapour mixture per pound of dry air.

Humidity Relative
The relative humidity of a gas (or air) vapour mixture is the ratio of the partial pressure of the vapour to the vapour saturation pressure at the dry bulb temperature of the mixture.

Hydrogen Chlorofluorocarbons (HCFC)
Chemical species slated to replace CFCs in the near future.

Impeller
The part of the rotating element of a dynamic compressor that imparts energy to the flowing medium by means of centrifugal force. It consists of a number of blades mounted so as to rotate with the shaft.

Indicator Pressure
An indicator that signals pressure conditions.

Induced Draft
An air flow caused by a fan that draws air through the heat exchanger core in a uniform pattern to dissipate the sensible heat.

Inert Gas
Is one that does not enter into known chemical combination, either with itself or another element. There are four known gases of this type: helium; neon; argon and krypton. or a gas that does not supply any of the needs of combustion.

Inlet Pressure
Is the total pressure (static plus velocity) at the inlet flange of the compressor.

Inlet Temperature
Is the temperature at the inlet flange of the compressor.

Instrument Air
A quality of compressed air for use with pneumatic instruments and controls. (usually dry and free from contaminants)

Intake Filter
A device for separating solids or suspended particles in the air before they enter the air intake of the compressor.

Intercooler
Heat exchangers for removing the heat of compression between stages of a compressor.

Intercooling
The removal of heat from the air or gas between stages.

Isentrop
Is a process taking place without any heat exchange with the surroundings.

Isentropic Power Consumption
The power which is theoretically required to compress a gas under constant entropy from a given inlet pressure to a given discharge pressure. (calculated assuming ideal conditions).

Isobar
Is a process taking place under constant pressure. To change the volume from state 1 to state 2, heat must be removed. The temperature change is proportional to the change in specific volume.

Isotherm
Is a process taking place under constant temperature. To compress the gas from state 1 to state 2, heat must be removed to keep the temperature constant. The pressure change is reciprocal to the change in specific volume.

Isothermal Compression
Is a compression in which the temperature of a gas remains constant.

Isothermal Efficiency
The ratio of the isothermal power consumption to shaft input.

Kinematic Viscosity
Is the dynamic viscosity divided by the density

Leak Air
A crack or hole that accidentally admits a gas or lets it escape.

Liner
Filter parts that provide protection and support for the filter media.

Loaded
A filter element so full of contaminants that no longer can pass rated flow without excessive pressure differential.

Lobe
A type of journal bearing in centrifugal air compressors.

Lubrication
A material (such as oil) used between moving parts of machinery to make the surfaces slippery and reduce friction.

Lubricator
An instrument designed to add lubrication into the compressed air line.

Maximum Operating Pressure
The highest operating pressure the system or component is designed to withstand.

Membrane Dryer
Reduce dew point by passing compressed air through a bundle of hollow membrane fibers; water vapour and a portion of the compressed air then permeate the membrane walls and vent to atmosphere .

Modulating Unload
The air compressor continues to run and air supply is matched to the demand by partial unloading. This can be accomplished by a regulator controlled floating inlet or by step unloading.

Moisture Separator
A unit designed to separate condensate from the compressed air stream.

Moisture Trap
A device designed to enable accumulated liquids to be held for draining in a compressed air system.

Molecular Sieves
A solid adsorbent used for drying compressed air.

Multistage Axial Compressor
A machine having two or more impellers operating in series on a single shaft and in single casing.

Multistage Centrifugal Compressor
A machine having two or more impellers operating in series on a single shaft and in single casing.

Multistage Compressor
A machine employing two or more stages.

Natural Frequency
A projecting aperture at the end of a tube, pipe etc. serving as an outlet for compressed air. Reduces the demand on the compressor by generating the highest thrust and volume for the lowest possible air consumption.

Negative Pressure
A pressure below that of the existing atmospheric pressure taken as a zero reference.

No Load
The air compressor continues to run, usually at full RPM, but no air is delivered because the inlet is either closed off or modified, not allowing inlet air to be trapped.

Nominal Efficiency
An arbitrary filter efficiency rating.

Nominal Filter Rating
Filter rating indicating the approximate particle size for which the majority will not pass through a given filter. It is generally interpreted as meaning that 85% of the particles of size equal to the nominal filter rating will be retained by the filter.

Nominal Micron Rating
A term that means that 98% of all particles larger than a stated micron size have been removed from the product being filtered through the filter element.

Non condensables
Are those constituents in the suction gas that cannot be condensed to a liquid with the cooling medium available.

Non cooled Compressor Cylinders
Reciprocating type compressor used mainly in oil and gas field applications. The compressor cylinders operate at low compression ratios and experience small temperature rise.

Nonlubricated Compressor
A compressor designed to compress air or gas without contaminating the flow with lubricating oil. Piston rings and packing are usually made of TFE-based materials or carbon or other synthetic material that operate without lubrication.

Normal Air
Is the term used for average atmospheric air at sea level in a temperature zone where it contains some moisture. It is defined in the ASME Test Code For Displacement Compressors as being at 14.696 psiA, 68 °F, 36% RH and weighing 0.075 lb/cu ft. The k value is 1.395.

Nozzle
A projecting aperture at the end of a tube, pipe etc. serving as an outlet for compressed air. Reduces the demand on the compressor by generating the highest thrust and volume for the lowest possible air consumption.

Nozzle (Valves)
The stationary seating surface, the inlet of a valve.

Oil Free Compressor
A positive displacement air compressor which has no oil injected into the compression chamber for lubrication, cooling or sealing

Oil System
Consists of a vessel which is a combination of oil sump and oil separator, an oil cooler and an oil filter.

Operating Pressure
The gauge pressure at which a pressure vessel is maintained in normal operation.

Operating Pressure Burst
Above this pressure, the system may rupture or burst.

Orifice
An opening such as a hole or vent. An opening through which air can pass, or a restricted opening placed in a pipe line to provide a means of controlling or measuring flow.

Overhung Type Centrifugal Compressor
A single inlet compressor with the impeller or impellers mounted on an extended shaft of the driver.

Overpressure Accumulation
The permitted increase in pressure developed after the valve has opened. Usually expressed in percentage, ie.; 3% accumulation (A.S.M.E. Code, Section I). Flows through safety/relief valves are officially determined at these overpressure conditions.

Package Power
The total power absorbed by a compressor, including the power absorbed by all pumps, fans, coolers and the like.

Paving Breaker
A hand held pneumatic tool. Designed for light demolition work, digging, making holes etc.

PDP
Pressure dew point temperature (°C).

Pedestal Type Centrifugal Compressor
A single inlet compressor with the impeller or impellers mounted on a shaft supported by two bearings in a pedestal, with the driver coupled to the compressor shaft.

Perfect Intercooling
Is obtained when the gas is cooled to first stage inlet temperature following each stage of compression.

Performance Curve
A plot of expected operating characteristics (eg., discharge pressure versus inlet capacity, shaft horsepower versus inlet capacity).

Permeability
The relationship of flow per unit area to differential pressure across a filter medium.

Piston Displacement
Net volume actually displaced by the compressor piston at rated machine speed, generally expressed in cubic feet per minute (usually CFM). For multistage compressors, the piston displacement of the first stage only is commonly stated as that of the entire machine.

Point Of Use
A single outlet or limited number of outlets in a building used to connect tools or equipment to the air system.

Pore
A small channel or opening in a filter medium which allows passage of gas.

Positive Displacement Compressors
Compressors in which successive volumes of air or gas are confined within a closed space, and compressed. They may be either reciprocating or rotating. (Trap air and then squeeze it to the desired pressure).

Pour Point
Is the temperature at which oil begins to flow under prescribed conditions.

Power Theoretical
The mechanical power required to compress polytropically and to deliver, through the specified range of pressures, the gas delivered by the compressor.

Pre-Cool
Pre-Cooling of intake air for compressors and Blowers.

Precooler
Is a heat exchanger located immediately preceding an ejector to condense and remove a portion of the vapour in the mixture and thus reduce the total lb/hr to be handled.

Pressure
Force per unit area, usually expressed in pounds per square inch (PSI) or BAR.

Pressure Absolute
The total pressure measured from absolute zero (i.e., from an absolute vacuum).

Pressure Back
The pressure encountered on the return side of a system.

Pressure Dew Point
Is the temperature at which moisture begins to condense in a compressed air system.

Pressure Discharge
Is the total gas pressure (static plus velocity) at the discharge port of the compressor. Velocity pressure is considered only with dynamic compressors.

Pressure Drop
Resistance to flow. Defined as the difference in pressure upstream and downstream.

Pressure Gauge
A device that indicates pressure differential above or below atmospheric pressure.

Pressure Inlet
Is the total pressure (static plus velocity) at the inlet flange of the compressor.

Pressure Rated
The qualified operating pressure which is recommended for a component or a system by the manufacturer.

Pressure Regulating Valve
A valve which enables pressure to be reduced, or kept constant at a desired level.

Pressure Rise
The difference between the discharge pressure and the intake pressure.

Pressure Static
The pressure measured in a flowing stream (liquid or gas) in such a manner that no effect on the measurement is produced by the velocity of the stream.

Psychrometry
Has to do with the properties of air-water vapour mixtures in the atmosphere.

Pulsation Damper
A small receiver fitted on the inlet or discharge of a reciprocating compressor. The device is designed to remove the resonance from the compressor thereby reducing noise. (188)

Pumping
Is the reversal of flow within a dynamic compressor that takes place when the capacity being handled is reduced to a point where insufficient pressure is being generated to maintain flow. Also known as surge.

Purge Air
The portion of dry, full line pressure, compressed air taken from the drying side tower of a dual tower desiccant dryer system. Expanded to a very low pressure and passed across the wet desiccant to strip the moisture in the desiccant of the regenerating tower. In the case of an external blower type dryer, the purge air is atmospheric air compressed by a blower and heated by an external heater to strip moisture off a wet desiccant bed.

Radial Compressor
A compressor belonging to the group of dynamic compressors. Characterized by radial flow. (Centrifugal)

Receivers
Tanks used for the storage of air discharged from compressors. They serve also to damp discharge line pulsations.

Reciprocating Compressors
Machines in which the compressing element is a piston having a reciprocating motion in a cylinder.

Recovery Pressure
Is that pressure of either motive fluid or discharge at which an ejector returns to stable operation following a period of unstable operation due to having previosly reached the breaking pressure. There are two recovery pressures, one for motive fluid and one for the discharge pressure.

Reduced Pressure
Ratio of the pressure of a gas to its critical pressure, in like units.

Reduced Temperature
Is the ratio in absolute units of the actual gas temperature to the critical temperature.

Refrigerant
Media of heat transfer in a refrigeration unit. R12 and R22 are commonly used refrigerants.

Refrigeration Dryer
A device consisting of a heat transfer system, a moisture elimination system and a refrigeration system designed to improve the quality of the air and reduce the temperature of the air.

Regulator
An automatic or manual device designed to control pressure, flow or temerature.

Reheaters
Heat exchangers for raising the temperature of compressed air to increase its volume.

Relative Clearance Volume
The ratio of clearance volume to the volume swept by the compressing element.

Relative Vapour Pressure
The ratio of the vapour pressure to the saturated vapour pressure at the temperature considered.

Rotary Blowers
A compressor belonging to the group of displacement rotary compressors, a type of valveless displacement machine. Also refered to as "Roots blower".

Rotary Compressors
Machines in which compression is effected by the positive action of rotating elements.

Rotary Sliding Vane Compressors
Machines in which axial vanes slide radially in an eccentrically mounted rotor.

Rotor
The rotating element of a machine and, in the case of a compressor, is composed of the impeller (impellers) and shaft, and may include shaft sleeves and a thrust balancing device.

Safety Valve
A device that limits fluid (liquid and gaseous) pressures by discharging some of the pressurized liquid or gas.

Safety Relief Valve
An automatic pressure relieving device actuated by the static pressure upstream of the device, which opens in proportion to the increase in pressure over the opening pressure.

Saturated Air Vapour Mixture
Is one in which the space occupied by the mixture is saturated with water vapour at the mixture temperature.

Saturated Vapour Pressure
Is the pressure existing at a given temperature in a closed vessel containing a liquid and the vapour from that liquid after equilibrium conditions have been reached. It is dependent only on temperature and must be determined experimentally.

Saturation
Occurs when the vapour is at the dew point or saturation temperature corresponding to its partial pressure. A gas in never saturated with a vapour. However, the space occupied jointly by the gas and vapour may be saturated.

Saturation Pressure
Is another term for saturated vapour pressure.

Scale
A coating or precipitate deposited on surfaces such as water pipes, steam boilers that are in contact with hard water. Water that contains carbonates or bicarbonates of calcium or magnesium are likely to cause scale when heated.

Screw Compressor
Is a positive displacement rotary compressor.

Seals
Devices used between rotating and stationary parts to separate, and minimized leakage between, areas of unequal pressures.

Seat
The stationary seating surface, the inlet of a valve.

Set Pressure
The gauge pressure at which a safety valve visibly and audibly opens or at setting which a relief valve discharges an unbroken stream of liquid.

Single Acting
The piston only compresses air with its stroke in one direction.

Single Stage Compressors
Machines in which air or gas is compressed in each cylinder or casing from initial intake pressure to final discharge pressure.

Silica Gel
A desiccant most commonly used in heat regenerative type dryers.

Single Stage Centrifugal Compressors
Machines having only one impeller.

Sleeve
A type of journal bearing in centrifugal air compressors.

Specific Energy Requirement
The shaft input per unit of compressor capacity.

Specific Fuel Consumption
The ratio of fuel consumption to compressor capacity.

Stages
Steps in the compression of a gas, In reciprocating compressors, each stage usually requires a separate cylinder, in dynamic compressors, each requires a separate rotor disc.

State
Of a system (or part thereof) is its condition at an instant of time as described or measured by its properties.

Stem
The rod connecting the disc to the lever on a valve.

Strainer
A device used to separate air solids from the stream of air that might become a source of trouble. Adulterants caught in the strainer are blown out throught an orifice fitted with a valve or plug. The strainer should be opened periodically for a thorough cleaning.

Stroke Total
The difference between the maximum extended height and the compressed height of an air actuator.

Stroke Usable
That part of the total stroke which can be utilized repeatedly in actuator applications. It is measured starting at the compressed height and is the difference between the compressed height and the actuator height limit.

Suction Pressure
This is the pressure found on the suction side of a refridgeration system.

Surge
Is the reversal of flow within a dynamic compressor that takes place when the capacity being handled is reduced to a point where insufficient pressure is being generated to maintain flow. Also known as pumping.

Surge Limit
In a dynamic compressor, surge limit is the capacity below which the compressor operation becomes unstable.

Swept Volume
term mainly used by companies selling small compressors because it makes their compressors look bigger than they really are. The swept volume is the actual displacement of the piston, forgetting such losses as bumping clearances, valve clearances, ring losses and the like. It's not unusual to see an advertisement offering a compressor with (say) a delivery of 30 cfm, swept. In reality the compressor will only deliver about 20 scfm.

Synthetic Lubricant
A lubricating oil made with synthetic base stocks.

Temperature Absolute
The temperature of a body referred to the absolute zero, at which point the volume of an ideal gas theoretically becomes zero. (Fahrenheit scale is minus 459.67°F / Celsius scale is minus 273.15°C).

Temperature Discharge
Is the temperature existing at the discharge port of the compressor.

Temperature Inlet
Is the temperature at the inlet flange of the compressor.

Temperature Intake
The temperature at the intake flange of the compressor.

Temperature Rise Ratio
Is the ratio of the computed isentropic temperature rise to the measured total temperature rise during compression.

Temperature Static
The actual temperature of a moving gas stream. It is the temperature indicated by a thermometer moving in the stream with the same velocity as the stream.

Torr
A unit of pressure used with vacuum pumps, equal to 1mm of mercury and 133.32 Pascal's.

Torque
Torsional moment or couple. It usually refers to the driving couple of a machine or motor.

Trunk Compressor
A compressor belonging to the group of displacement reciprocating compressors.

Trunnion
A device for mounting cylinders.

Two Stage Compressor
Machines in which air or gas is compressed from initial pressure to an intermediate pressure in one or more cylinders or casings.

Two Step Control
Load/unload control system that tries to maximizes compressor efficiency by matching air delivery and air demand. Compressor is operated at full load or idle

Ultrasonic leak detector
An instrument designed to detect the ultrasonic emissions and convert them to audible signal.

Unit type compressors
Compressors of 20 HP or less, generally combined with all the components required to put the into operation.

Unload
The air compressor continues to run, usually at full RPM, but no air is delivered because the inlet is either closed off or modified, not allowing inlet air to be trapped.

Unloaded Horsepower
The power that is consumed to overcome the frictional losses when operating in an unloaded condition.

Utilisation Factor
The ratio in percentage of the time that the equipment is in operation to the total working time.

Vacuum Pumps
Compressors that operate with an intake pressure below atmospheric and discharge pressure usually atmospheric or slightly higher.

Valves
Devices with passages for directing flow into alternate paths.

Vane Compressor
Is a single shaft, positive displacement rotary compressor.

Vane Material
Most common material is phenolic resin-impregnated laminated fabrics, such as asbestos or cotton cloth. For oil free service, bronze and carbon/graphite vanes are used.

Vapour
Fine separated particles floating in the air and clouding it. A substance in the gaseous state.

Vapour pressure
Is the pressure exerted by a vapour confined within a given space. The vapour may be the sole occupant of the space, or may be associated with other gases.

Varnish
The oxidation of conventional hydrocarbon lubricants when they reach the end of their useful life and begin to breakdown. Can cause operating temperature increase, increase brake horsepower and plugs separator, can destroy air end.

V belt drive
A drive arrangement for power transmission to compressors.

Viscosity
Is a measure of resistance to deformation, or reluctance to be squeezed out a bearing. Indicates the internal friction of a fluid. Viscosity in normal lubricants is reduced as temperature increases

Viscosity Index (VI)
Is a measure of the rate of change of viscosity with temperature. Oils with high VI have low viscosity changes.

Volumetric Efficiency
The ratio and percent of the actual delivered capacity (measured at inlet temperature, pressure and gas composition) to the piston displacement.

Volute
A stationary, spirally shaped passage that converts velocity head to pressure.

Voting Alarm
(Compressors/Gas Turbines) Is an alarm system that has maybe 3 sensors connected to it and it will require minimum of 2 of the 3 to alarm before the alarm will act. There is a controller connected that does the logic decision based on set parameters.

Water Cooled Compressors
Machines cooled by water circulated through jackets surrounding the cylinders or casings.

Wet Bulb Temperature
Is used in psychrometry and is the temperature recorded by a thermometer whose bulb has been covered with a wetted wick and whirled on a sling psychrometer. Taken with the dry bulb, it permits determination of relative humidity of the atmosphere.

Work
Is energy in transition and is defined in units of Force times Distance. Work cannot be done unless there is movement.

Working Pressure
The normal working pressure for an air motor (6 bar).

IS: 6206 - 1985

Table.1 : Approximate Air Consumption Of Pneumatic Machine Tools

Description of Pneumatic Machine	Free Air Consumption at 6.0 to 6.5 bar (m^3/min)
Core blower	0.65
Rammer, bench (2.7 to 5.5 kg)	0.30 - 0.65
Rammer, floor type (8.5 to 11.4)	0.35 - 0.8
Moulding machine	0.70
Sand blast (shot):	
8 mm jet	3.00 }
9mm jet	4.30 } at 4.2 bars
11mm jet	5.80 }
13mm jet	7.0 }
Blow gun	0.50
Fettling grip or vice	0.0035 per operation
Hot miller (1 or 2 cutter)	0.9 per cutter
Air hoist:	
0.5 t	2.00
1 t	2.50
1 t	5.80
Chipping hammer:	
light (up to 2 kg)	0.35 - 0.50
medium (up to 4 kg)	0.50 - 0.70
heavy (up to 6 kg)	0.75 - 1.00
Wood deck caulker	0.70
Riveting hammer:	
20 -25 mm hot rivets	0.68 - 0.73
31 mm hot rivets	0.82
34 mm hot rivets	1.00
Rivet buster, heavy single blow type	0.10 per rivet

Rivet cutter, rapid blow type for rivets Up to 20 mm	1.00
Riverter, single below ('One shot' for air-craft rivets	0.18 for 100 rivets
Riveter, staybolt for 25 mm copper staybolts Chipper, weld flux	1.00 0.75
Sander	0.30
Tube cutter for tubes: 62 mm 62 - 100 mm	 1.35 1.65
Tube expander for tubes up to: 62 mm 75 mm 100 mm	 1.35 1.65 1.90
Scaling hammer" valveless, for surface work for larger boiler tubes	 0.20 0.60
Grinders: 13 - 20 mm dia wheels up to 50 mm dia wheels up to 100 mm dia wheels up to 150 mm dia wheels up to 200 mm dia wheels	 0.25 0.75 1.20 1.30 1.50
Angle grinders and polishers	0.75

Drilling machine for:	
6 mm holes in steel	0.37
9 mm holes in steel	0.45 - 0.60
13 - 20 mm holes in steel	0.75 - 0.90
22 - 25 mm holes in steel	1.0 - 1.20
32 mm holes in steel	1.30 - 1.75
38 mm holes in steel	1.50 - 1.60
50 mm holes in steel	1.65 - 1.80
75 mm holes in steel	1.80 - 2.40
For wood boring, air consumption for the immediately smaller size shall be taken. For reaming and tapping in steel, air consumption	
Wrenches (rotary type) for:	
7 mm nuts	0.15 - 0.25
9 mm nuts	0.45 - 0.50
13 - 20 mm nuts	0.75 - 1.00
22 - 25 mm nuts	1.0 - 1.20
	2.0
Wrench, impact for nuts up to:	
20 mm	0.60
32 mm	1.10
Wrench, tapping	0.45
Saw, 150 mm dia	0.60
Air chuck or arbor	0.003 per operation
Air lift pump	Considerable variation according to prevailing conditions
Sump pump 400 - 1000 1/min	1:50 - 3.60
Air press	0.0007 per operation

Air motors:	
Up to 1 kW	1.2 to 1.35 per kW
1 up to 5 kW	1.2 per kW
over 5 k/w	1.0 per k W
Air cylinder	0.15 per meter - tonne of lift
Drill sharpener:	
Small	1.50
Large	3.60
Forging hammer (power):	
50 kg	1.80
150 kg	3.90
250 kg	5.70
500 kg	9.60
1 t	16.00
Concrete breaker:	
35 -40 kg weight	1.65 - 2.2
25 kg weight	1.35
15 kg weight	0.90
Pile driver	1.80
Spike driver	1.80
Stone tool for:	
Lettering and light carving	0.17
Medium dressing	0.30
Roughing and bushing	0.40
Stone surfacer, for large blocks	0.90
Spike puller, per spike	0.10

Cement gun:	
Small	3.00
Medium	4.80
Grouting machine	Variable up to 3.00 at 2.5
Internal vibrator, internal diameter:	
62 mm	1.10
75 mm	1.50
112 mm	2.00
140 mm	2.50
Shuttering vibrators:	
3 kg	0.18
4.5 kg	0.30
6 kg	0.45 - 0.60
Concrete comapactor	0.18 - 0.30
Rock drills:	
Driter drill ('cradle mounted)	
75 mm	3.70
88 mm	4.80
100 mm	5.70
Wagon drill with:	
100 mm drifter	6.30
88 mm drifter	5.20
Hand hammer drill (Jack hammer):	
14 kg weight	1.50
17 kg weight	1.90
22 kg weight	2.25
30 kg weight	2.70
Plug drill	0.90

Sinker drill: 75 mm 88 mm	 3.75 4.80
Stopping drill: Light Heavy	 2.00 3.75
Dustless dry drill: 88 mm 75 mm	 5.40 3.60
Underwater drill	2.50 - 2.70
Auger drill, for coal	2.24
Coal cutter, percussive: 62 mm 88 mm 100 mm	 3.00 4.30 5.40

Various energy saving retrofits are prevalent in compressed air systems. However, these have not yet made their presence widely felt, mainly due to certain constraints such as lack of awareness of the technology or financial constraints. A few are briefly discussed in this section, highlighting the areas of application, expected energy savings and investment cost. For information for our esteemed readers, the names and addresses of suppliers of such retrofits are also included.

Product : IEG Gossler precool system for an air compressor

Precool system is basically an air chilling plant attached to the suction side of the compressor. It comprises of usual component parts of refrigeration cycle i.e., compressor, condenser, expansion valve and evaporator.

Principle of Operation

The efficiency of the compressor is further improved by cooling the air prior to entering into compressor. As the temperature of air is reduced, its volume reduces and greater volume of air is available to the compressor. Therefore due to precooling either more air is delivered for a given power input or lesser power input is required for a given volumetric flow rate.

Air, which is sucked by the compressor passes through a specially designed evaporator where the moisture gets eliminated as the air passes through its dew point and freezing point of water.

Expected Energy Savings

The total energy saving for the compressor plant could be up to 30% against an operating cost of approximately 8%, which gives a net energy saving of atleast 20%.

Areas of Application

This can be applied in any type of industry where the compressed air usage is very high and require dry air.

Supplier

IEG Gossler is an Austrian company and their Indian representative is Perfect Consulting Engineers, New Delhi.

Perfect Consulting Engineers
Compressor Technology
A-18, Priyadarshini Vihar
IP Extension
New Delhi - 110 032.
Fax: 011-244009/ 244028
Tel: 2242226/ 2222775

Energy Efficient System of Using Air Compressors

Principle of Operation

More often, the air compressors are not used in the optimal way. The compressor units are usually switched on and normally operate through all the working shifts. If there are three shifts of working, the compressor units are pressed into service almost without any switching off. Such operations render the system more energy inefficient and also may result in excessive wear and tear of the units.

The proposed compressor monitoring and control system would consist of the following features.

- Energy efficiency compressors to be based loaded.
- Sequential switching on and off.
- Close monitoring of system by P.L.C.
- Serial port for computer.

Expected Energy Savings

Energy savings are due to:

- Selection of high efficiency compressors for continuous operation (or higher number of hours of operation).
- Minimising the no load running of the compressors

For a typical case of a bank of five compressors having effectiveness of 60-85%, motor power off take of 100 kW, and a period of unloading of 30%, the energy savings are estimated to be about 30,000 kWh per annum. This calculation is based on the assumption of 40% power consumption during unloading and about 7000 operating hours in a year.

Areas of Application

All industrial units where air compressor banks are used. They may be working on 3 shift basis.

Supplier
M/s. Mundewadi Engineers Services Pvt. Ltd.
"Bhooshan" 24, Gururaj Society, 137/4, Kothrud
Paud Road, Pune - 411 029
Phone # 342435

VSD for Motors

Principle of Operation

This is control technique where in AC digital drive used for the specific variable torque demands of Fan & pump loads as against the current industry practice of employing commercially available over rated constant torque machine control.

Areas of Application

Fans & Pumps are ideal applications since they, by far form the most common applications to be found in any manufacturing plant. Also they are invariably used in uncontrolled fashion with mechanical means of flow controls e.g., through vanes, Dampers & throttles. These can find application in other areas like :

Compressors
Material handling
Cranes/ Hoists
Chemicals
Food & beverage
Water & Waste
Textile
Sugar
Machine tool
Strip Forming
Wire & Cable
Rubber & Plastics
Mining
Steel
Theatre
Tobacco

Energy Saving Potential

The energy saving potential with the use of AC Drives varies with application and variable load / torque requirements.

Supplier

Control Techniques India Ltd
117- B . Developed Flats, Industrial Estate Perungudi, Chennai 600 096
Phone: 044 4961123/4961130/4961083, Fax : 044 4961602

Auto-Drain valve (Compressed air condensate discharge)

Principle of Operation

Compressed air condensate is collected in a container of drain valve. So that the capacative level sensor signals at the maximum point, the solenoid valve is then energised, closing the pilot supply line and allowing venting of the air above the valve diaphragm. The diaphragm lifts off the valve seat, the pressure in the housing forces the condensate into the discharge pipe. The electronic system of the auto-drain valve, condensate drain now calculate the discharge rate down to the exact maximum necessary valve opening time. The valve will again be fully closed and leakproof before any compressed air can escape.

Energy Saving Potential

Energy saving depends on the amount of condensate from receiver. Depending upon variation in humidity and amount of time present condensate valves opened for condensate removal, present air leakage from drain valve energy savings will vary.

Areas of Application

Compressed air receivers

Supplier

Pace Equipment Pvt. Ltd
27 Q&R. Laxmi Industrial Estate, New link Road, Andheri (West),
Mumbai 400 053
Tel : 022-626 5239, Fax : 022-620 2557

Free Air Delivery (FAD) Test

All compressors are designed to deliver a certain quantity of air per minute at a specified pressure.

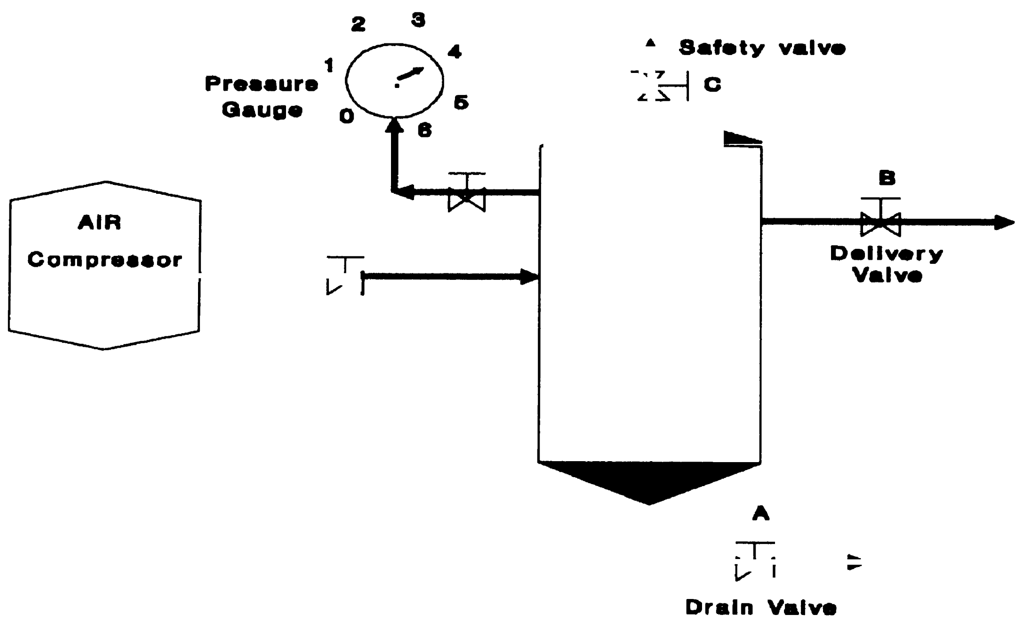
Example : *A compressor rated for 30 m3/min and 7.0 bar pressures takes in 30m3/min of free air from the atmosphere at ambient pressure and compresses it to a pressure of 7.0 bar.*

During commissioning of the compressor, the FAD test is conducted to assess the capacity of the compressor. Due to poor maintenance or ageing, the compressor may not deliver the rated quantity of air, although the power consumption has remained unchanged. The FAD test, conducted at regular intervals, is able to verify the performance of the compressor vis-à-vis the rated capacity. There are two methods for the FAD test, of which the former is more prevalent:

A. Pump Up Method :

FAD is evaluated by measuring the time taken to fill the air receiver up to its designed pressure. By determining the receiver volume, the interconnecting pipe line volume and the outlet air temperature, the actual FAD can be estimated.

Fig 1 : FAD Assessment - Pump Up Method



The actual steps are described with reference to Fig. 1.

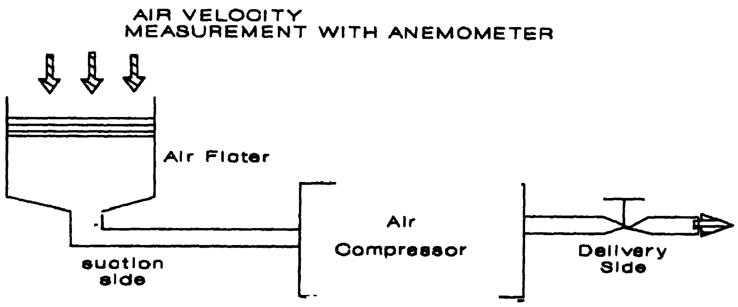
- *Switch off compressor*
- *Open valve A*
- *Wait till air pressure in receiver drops to zero*
- *Close valves A, B & C*
- *Start and load compressor, simultaneously starting stop watch*
- *Switch off compressor and record unloading time and pressure*
- *Measure outlet air temperature*
- *Calculate volume of air receiver and interconnecting pipe lines*

FAD in $m^3/min = \frac{A}{B} \times \frac{C}{D} \times \frac{E}{F}$

where A = Volume of air receiver and interconnecting pipe lines in m3/min
B = Time taken to fill receiver in min
C = Cut off or final air pressure in kg/cm^2a
D = Atmospheric air pressure in kg/cm^2a
E = Inlet air temperature in K
F = Compressed air exit temperature in K

B. Suction Velocity Method

Fig 2 : FAD Assessment - Suction Velocity Method



In this method, the average air velocity at the suction side is measured during compressor loading, using an anemometer. The suction hood may be removed and the duct extended using a sheet of cardboard to facilitate the measurement.

FAD in m^3/min = Suction air velocity in m^3/min x Area of duct cross section in m^2

Quantification of Compressed Air Leakage (No-Load Test)

Leaks obviously waste energy, and reduce the effective capacity of compressor plant and may, in extreme cases, reduce significantly the performance of the equipment using compressed air. Ideally speaking, a compressed air system should not have any leaks at all, but in practice it is very difficult to have a zero leakage system. Depending on the industry and type of air usage, the allowable air leakage varies. Generally it should be within 5% of the total compressed air generated. In almost all industries, a hissing sound generated from leaking pipe joints, valves, couplings, air regulators and other leak - prone areas is heard. Generally, this hissing is ignored, as nobody has quantified the air wastage.

A no load test should be conducted periodically, preferably on a day when there is no production in order to quantify the air leakage and maintain it to an acceptable minimum level. The procedure for a no load test is described below, with reference to Fig. 3.

- Switch off compressor
- Close valves A, B
- Open valves C, D
- Close valves 1 to 10
- Start compressor and allow the pressure to build up
- Note unload time
- Note load time
- Repeat exercise four or five times
- Switch off compressor

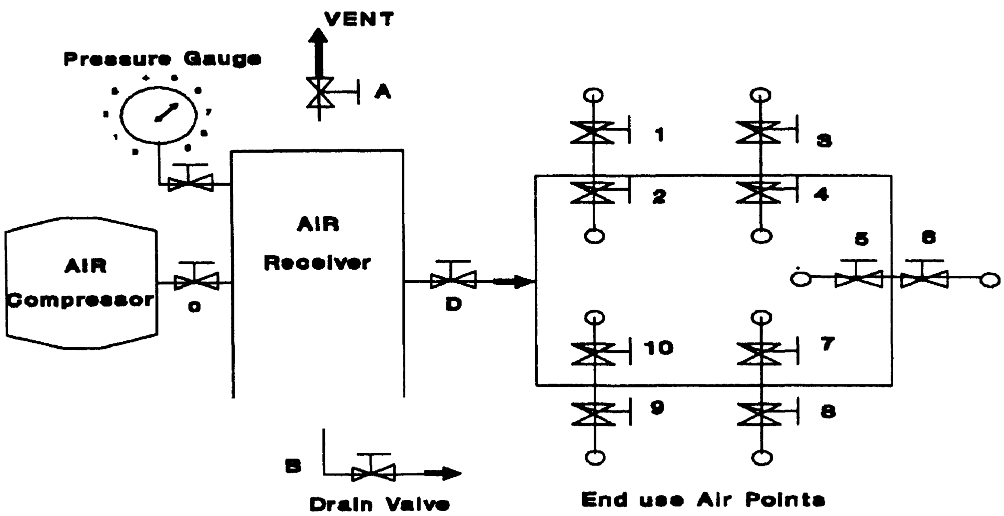


Fig 3 : No Load Test

Substitute the loading and unloading times in the equation below :

$$L = \frac{Q \times T}{(T + t)}$$

Where,

L = Total system leakage in cfm or m^3/min
Q = Actual free air delivery capacity of compressor in cfm or m^3/min
T = On load time in min (average)
t = Off load time in min (average)

Cost of Electrical Energy wasted due to leakage :
L x Sp. energy consm. (kW/cfm or kW/m^3/min) x run hrs/year x energy cost (Rs./kWh)

Power Consumption

During air compression, the power supplied to the shaft is used to increase the internal energy of the air by increasing its pressure and temperature. If the air temperature is reduced to attain its intake temperature, the compression approaches isothermal compression otherwise it is known as adiabatic compression. Isothermal compression consumes less power than adiabatic compression.

$$L = S \times \frac{k}{k-1} \times \frac{PsQ}{6120}\left\{\left(\frac{Pd}{Ps}\right)^{\frac{k-1}{ks}} - 1\right\} \times \frac{\phi}{\eta_e \eta_t}$$

The actual power required by compressor

The theoretical power required by compressor

$$L = S \times \frac{k}{k-1} \times \frac{PsQ}{6120} \left\{ \left(\frac{Pd}{Ps} \right)^{\frac{k-1}{k\,s}} - 1 \right\}$$

Where,

L = Required power in kW
P_s = Suction pressure in kg/m^2.a
P_d = Discharge pressure in kg/m^2.a
Q = Air delivery in m^3/min
S = No.of stages
k = Adiabatic constant of air (1.4)
η_e = Overall adiabatic efficiency of compressor (given by manufacturer)
η_t = Transmission efficiency (given by manufacturer)
ϕ = Allowance rate

Appropriate values of ϕ can be selected depending upon the type of compressor, as shown below:

Reciprocating compressor	= 1.10
Lubricated type screw compressor	= 1.10
Non lubricated type screw	= 1.15
Turbo compressor	= 1.2

Compressor Efficiency
The term 'efficiency' as applicable to a compressor is slightly different, as it involves three types of efficiencies, namely volumetric, isentropic and isothermal efficiency.

Volumetric Efficiency $= \dfrac{\text{Actual Volume of Air Delivered (m}^3\text{/min)}}{\text{Piston Displacement (m}^3\text{/min)}}$

Isentropic Efficiency $= \dfrac{\text{Adiabatic Power for Compression}}{\text{Actual Power Input to Compressor}}$

Isothermal Efficiency $= \dfrac{\text{Isothermal Power for Compression}}{\text{Actual Power Input to Compressor}}$

The volumetric efficiency decreases with increasing delivery pressure. As the isothermal and isentropic efficiencies are different, while comparing compressor efficiency, it is important to compare only the corresponding efficiencies. The more practical way of comparing compressor efficiency is based on the actual specific power consumption (i.e.,kW consumed per m^3/min FAD).

Estimation of Pressure Drop in Air Distribution System

The air mains and their associated branches, hoses, couplings and other accessories offer considerable opportunities for energy conservation. Excessive drops in pressure due to inadequate pipe sizing, choked filter elements, improperly sized couplings and hoses, and leaking pipe joints all contribute to a waste of energy.

The pressure drop in the distribution system should be maintained as low as possible, by installing proper sizes of pipes and other accessories. To ascertain the pressure drop:

- Arrest all leakage
- Install pressure gauges at different locations
- Switch off compressor
- Close all air consuming points
- Open air delivery valve
- Start compressor and build the pressure up to the operating pressure
- Note down pressure readings simultaneously at all the pressure gauges installed at various locations (P1, P2, P3, P4, P5, P6 & P7)
- Difference in pressure between air receiver at compressor house and other pressure gauges will indicate the actual pressure drop.

If the pressure drop is high, replace that particular section with a bigger pipe diameter. The selection of an economical pipe diameter for minimum pressure drop can be obtained from the given formula or can be selected from the nomogram.

Empirical Method

$$\text{Pressure drop (bar)} = \frac{KLQ^2}{Rd^{5.3}}$$

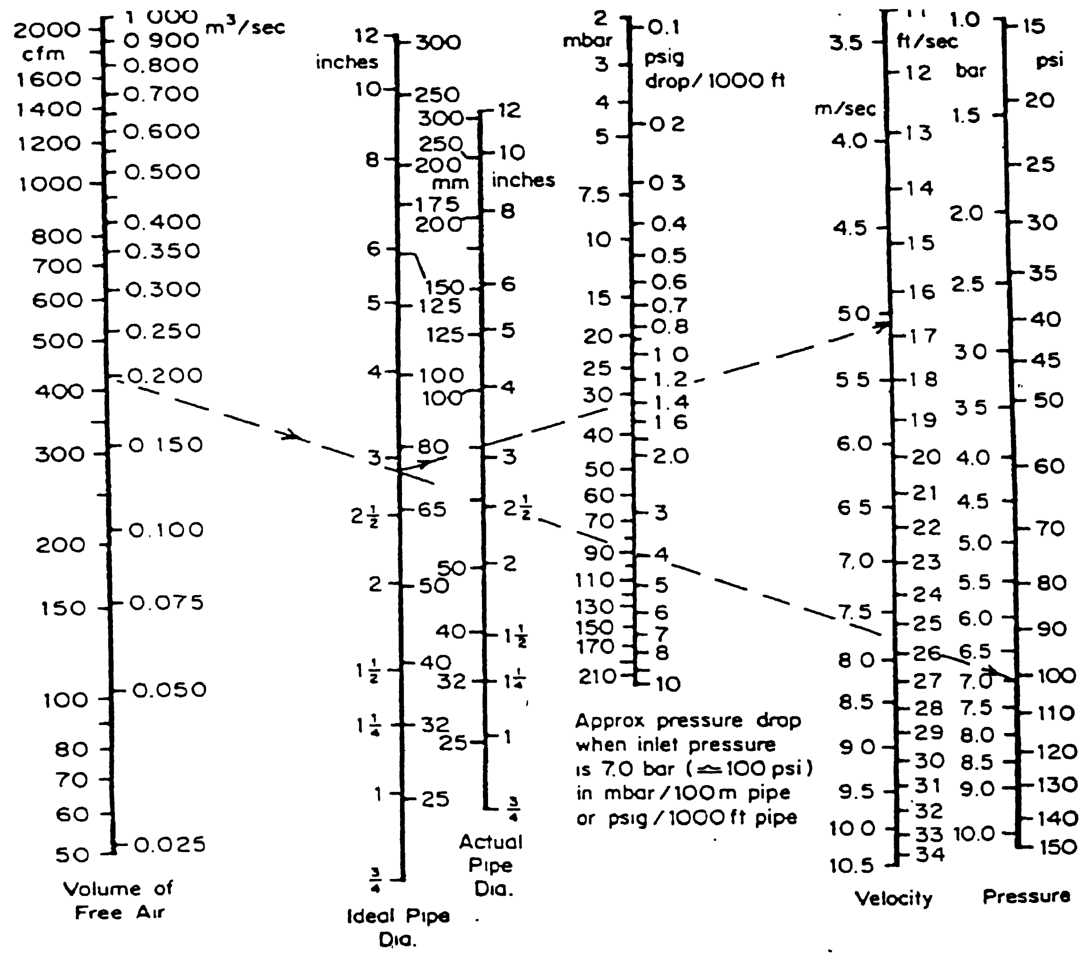
Where,

K = 800
L = Length of pipe in metres (including Equivalent Length of all fittings)
Q = Volume flow rate of free air l/s
R = Compression ratio
d = Internal pipe diameter in mm

Nomogram for Optimum Delivery Pipe Sizing

The nomogram in Fig.4 allows pipe sizes to be chosen to give compressed air velocities of 6m/s. As an example, consider an air compressor with an output of 0.2 m3/s free air at 7 bar. Place a ruler on 0.2 on the left-hand line and 7 on the right-hand line. This shows, as it crosses the second line, that the ideal pipe size would be just over 70 mm, but this is not a standard size. Take the intersection point from this second line to the size of pipe actually available, on the third line, say 80 mm and project a new line to cross the fourth and fifth lines. This shows an actual pressure drop of 33 mbar/100m and the actual velocity in such a pipe is 5.2 m/sec. While estimating length of pipe, add allowances, as equivalent pipe length for bends, tees and valves. Ensure adequate provision for water to be drained off throughout the system. The use of too small a pipe creates excessive pressure losses and so wastes a part of the input power to the compressor.

Fig. 4 : Nomogram for Pipe Sizing



Source : NIFES training manual issued for CEC-India. Energy Bus Project, June 1990.

Appendix 5 : Energy Audit Approach and Methodology

Preliminary Energy Audit (PEA)

PEA is a preliminary data gathering and analysis effort in two parts: (a) the energy management audit, wherein the auditor acquaints himself with investment decisions and criteria referencing energy conservation projects and (b) the technical energy audit using available data.

The energy auditor relies on his experience to gather all relevant written, oral or visual information that can lead to a quick analysis of the existing energy situation. It focuses on the identification of obvious sources of possible improvement in energy use, such as missing insulation, steam and compressed air leaks, inoperative instrumentation and superfluous operation. The typical output of a PEA is a set of recommendations for immediate low-cost actions and, usually, a recommendation for a detailed energy audit.

Detailed Energy Audit (DEA)

This is a measured survey followed by a plant energy analysis. Sophisticated instruments, such as flow meters, psychrometers, flue gas analysers and infrared scanners are used to enable the auditor to compute efficiency and balances during typical equipment operation. The tests performed and instruments required depend on the type of facility, the objective, scope and level of handling of the energy management programme. The tests conducted include combustion efficiency tests, measurement of temperature and airflow of major fuel-using equipment, determination of power factor degradation caused by various pieces of electrical equipment and testing of process systems for operation within specification.

After obtaining the results, the auditor validates them using preliminary computation and existing support materials such as tables and charts. Then, he builds energy and mass balances, first for each major piece of equipment tested, and then, for the plant as a whole. From such balances, he can determine the energy efficiency of each equipment and scope for possible improvement in efficiency, with costs and benefits of selected options for each opportunity. In some cases, he is unable to recommend a specific investment because of its magnitude or the associated risk. In such a case, he may recommend specific feasibility studies such as boiler replacement, furnace modification, steam system replacement and process changes. The detailed report presents the auditor's recommendations, with costs, benefits and implementation aspects.

Steps in Energy Audit Programme

In an Energy Audit, detailed data are collected and analysed. Although sophisticated instruments are used, energy auditing is not an exact science. The auditor must use his knowledge and judgement to collect and interpret data suitably. The various steps in an energy audit programme are given below:

Step 1. Review energy management programme to date

The programmes are customarily reviewed with senior corporate staff. The auditor can decide what changes may be needed in the scope of the proposed detailed energy audit. If there is no formal programme, the auditor will try to understand why.

Step 2. Conduct preliminary energy audit

The preliminary energy audit (PEA) should be conducted after the review. The PEA consists essentially of gathering and analysing data. It uses available data only, without the use of sophisticated instruments. The results of the PEA depend on the ability and experience of the auditor. The output of the PEA is normally:

- Development of energy consumption / cost data base for a facility
- Objective evaluation of plant condition

- Identification of major energy-consuming systems
- Understanding of company policies for energy-related projects
- Action plan for future energy auditing work

The PEA generally has six steps.

1. Organise resources
- Manpower / time frame
- Instrumentation

2. Identify data requirements
- Data forms

3. Collect data

a. Conduct informal interviews
- Senior Management
- Energy manager/co-ordinator
- Plant engineer
- Operations and production management and personnel
- Administrative personnel
- Financial manager

b. Conduct plant walkthrough/visual inspection
- Material / energy flow through plant
- Major functional departments
- Any installed instrumentation, including utility meters
- Energy report procedures
- Production and operational reporting procedures
- Conservation opportunities

4. Analyse data

a. Develop database
- Historical data for all energy suppliers
- Time frame basis
- Other related data
- Process flow sheets
- Energy - consuming equipment inventory

b. Evaluate data
- Energy use - consumption, cost, and schedules
- Energy consumption indices
- Plant operations
- Energy saving potential
- Plant energy management programme

5. Develop action plan
- Conservation opportunities for immediate implementation
- Projects for further study
- Resources for detailed energy audit
  - systems for test
  - instrumentation - portable and fixed
  - manpower requirements
  - time frame
- Refinement of corporate energy management programme

6. Implementation

- Implement identified low cost/no cost projects
- Perform Detailed Audit

Step 3. Develop action plan, including detailed energy audit

On the basis of the review and the PEA, the energy auditor should develop an action plan, including a Detailed Energy Audit (DEA), considering:

- Management of energy-related matters
- Monitoring and reporting considerations
- Relationships with manufacturers' representatives
- Availability of resources for implementing the action plan

Step 4. Select scope of detailed energy audit

The next step is to determine the scope of DEA, in order to finalise resources requirement in the following areas:

- Manpower: Manpower required for the DEA should be selected, on the basis of the review of the PEA, from internal or external sources.
- Instrumentation: The DEA provides the basis for the quantitative analysis of the energy performance of the facility. To compile the operating data necessary to make this quantitative assessment, a variety of fixed and portable instrumentation is used.
- Testing procedures: There are standard testing procedures for evaluating equipment performance, which the auditor may use as guidelines. For example, BIS 8753 provides methods for calculating the combustion efficiency.
- Cost for conducting the DEA: This depends on the time required to complete the DEA, in other words, the size of the plant and the report preparation time. The use of sophisticated instrumentation and overheads also add on to the cost of the DEA.

Step 5. Complete preparatory work

All instruments should be calibrated, serviced and/or repaired, additional instruments purchased and test measuring positions and connections completed. The auditor should make sure that the time selected for the audit does not conflict with the operation of the equipment to be tested or the plant in general. The testing date should also be representative of normal plant operation.

Step 6. Carry out detailed energy audit field work

The energy auditor can now conduct the fieldwork for the DEA, which comprises two main tasks:

The first task is to gather data to evaluate all energy aspects using the PEA as a starting point, expanding on it, to fill gaps and learn more about the plant operation.

The auditor usually interviews selected personnel, examines records, observes operations, monitors and checks conditions. This may involve repeated data collection and review.

The most important part of an energy audit consists of the preparation of energy and material balances, first for individual equipment operations and then, for the entire plant. Without such data, it is rarely possible to carry out quantitative analyses to identify potential energy savings. Instruments play a vital role in measuring, indicating and controlling process parameters to achieve energy efficiency.

The second task is to perform tests on selected equipment to evaluate its efficiency.

Step 7. Evaluate collected data

Based on the raw data generated, efficiency of various equipment is evaluated. This involves detailed calculation, using computers and at times, specially designed software.

Step 8. Identify conservation opportunities

The results of the evaluation can be used to identify the energy conservation opportunities:

- Better operation and maintenance by low-cost housekeeping measures
- Recovery of waste energy
- Improvement in equipment efficiency
- Installation of advanced control systems
- Change of technology

These low cost opportunities require little or no major capital investment and have immediate returns on investment. On a simple payback basis, they have paybacks of less than a year.

Capital-intensive measures require large investments. Simple payback periods are usually more than a year. The auditor should use payback period as a guideline, while making his list of recommendations. He should also keep in focus, the attitude of the management towards capital-intensive projects.

Step 9. Develop action plan of implementation

The auditor will probably not have the authority to implement the measures identified, especially if capital requirements are large. Instead, he will complete a report, which will present his findings, with a concrete and time-bound action plan.

It should usually be possible to implement some O&M measures immediately. However, capital intensive measures may require feasibility studies before a decision can be made to implement them.

An action plan often includes a recommendation for self-financing. In a self-financing programme, O&M changes are implemented and the resulting cost benefits are invested directly in lower-cost capital-intensive measures to bring in more savings. Eventually, these savings are used to pay for the most capital-intensive measures.

Step 10. Continue to monitor energy use

Energy efficiency in a company cannot begin and end with the DEA. To sustain its energy efficiency, a company must continue to monitor its energy use.

The DEA report should recommend improvements to the existing monitoring and reporting procedures for energy use. Very few companies, if any, have an adequate system of monitoring procedures. Without such a system, it is hard to spot changes in consumption that result from increase or decrease in efficiency. Possible improvements that can be made to monitoring and reporting procedures include:

- Upgrading of instrumentation
- Development of energy consumption indices
- Development of energy models

Step 11. Refine overall energy management programme

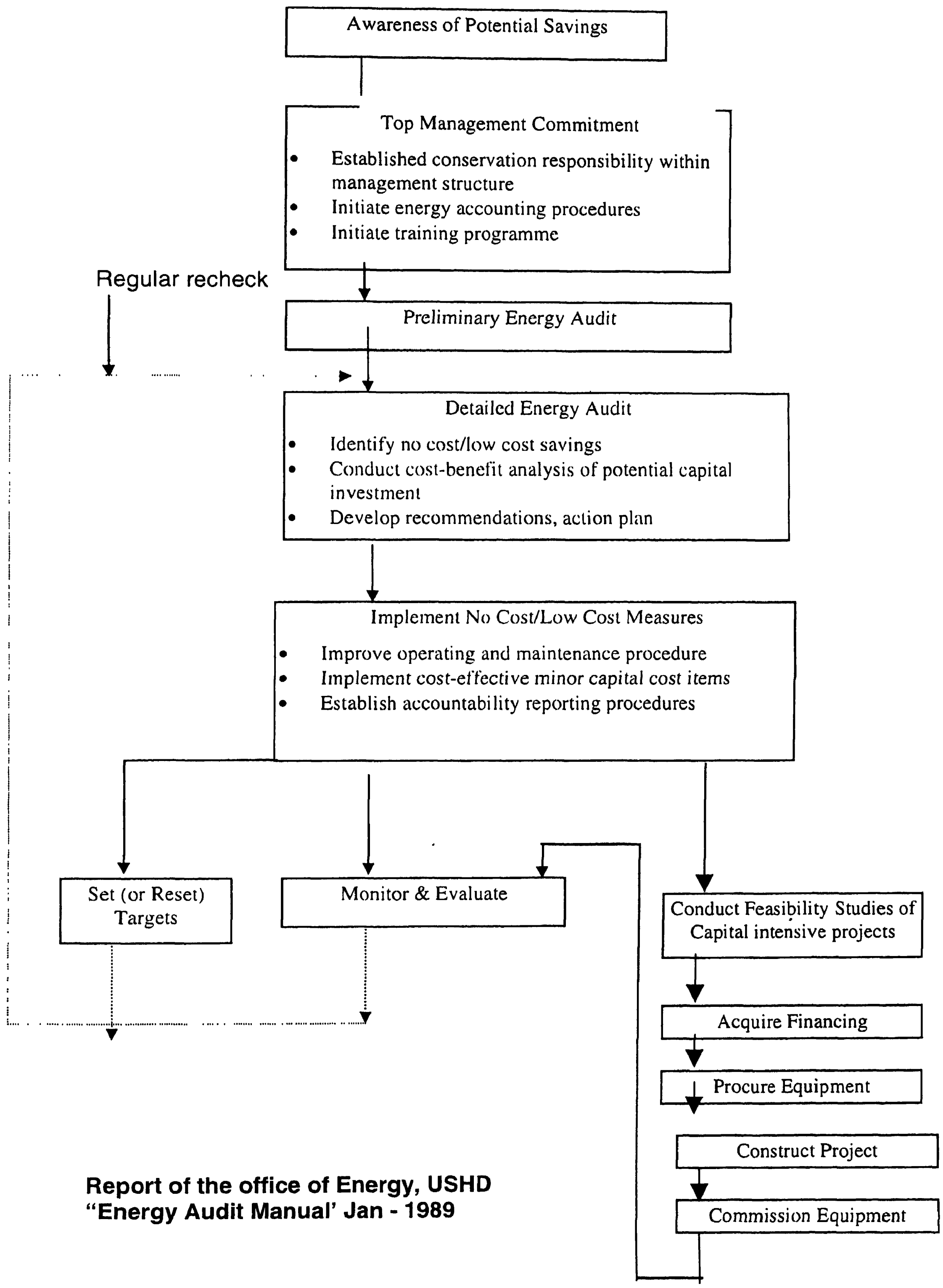
The major recommendations of the DEA should be refinements to the overall corporate energy management programme. Since energy affects so many aspects of operations, improvements in energy use cannot take place without commitment at the highest levels of management and a proper organisational framework. The management's perception of the state of energy use will determine the success of any energy management programme. Recommendations may include:

- Appointing personnel to be responsible for energy
- Formally structuring a corporate energy management programme
- Training staff and employees in energy awareness

In its efforts to maintain energy consumption within levels consistent with technological developments, the management may carry out regular energy audits to review the results of the improvement measures.

ENERGY MANAGEMENT PRACTICE

The energy management process in totality can be represented as below:



Source: **Report of the office of Energy, USHD "Energy Audit Manual' Jan - 1989**

Appendix 5 : Energy Audit Approach and Methodology

The Approach to Energy Management

The commitment of top management should be clearly demonstrated in policies and directives, with company decisions to control costs being clearly defined. Active participation in energy related activities by senior management is a vital step in this approach. Chart A presents this concept schematically. Practising energy management includes mandatory functions such as:

- Identification of possibilities for further improvement
- Evaluation of these opportunities to prioritise them
- Implementation of conservation measures
- Continuous monitoring to sustain and further improve upon these measures

Preliminary Analysis

In order to develop an energy management programme, it is necessary that the scope, extent of detail and the management cost and time expended should have some relation to the potential benefits of the programme. The cost incurred should not be more than the value of energy saved. The preliminary analysis should include with a preliminary analysis of parameters such as:

- Consumption of various forms of energy
- Energy cost as percentage of production cost
- Major energy intensive equipment
- Potential savings and comparison with current profit
- Cost of additional metering possibly required to introduce the programme
- Efforts within existing framework to monitor energy consumption in different departments.

Such a broad evaluation would give a perspective of the management time and cost value in relation to potential returns.

Energy Committee

Within the company, and particularly for larger industries, an Energy Committee would play a vital role of co-ordination between various departments. This may, for example, include senior managers, the Accountant and the Chief Engineer. Since accountability and authority go hand in hand, the Chairman should be a senior functionary, with authority to ensure that all resources are made available for necessary actions.

The Committee will be responsible for:

- Developing the energy policy
- Managing the monitoring system
- Concurring upon and reviewing standards and targets
- Examining energy saving schemes
- Ensuring project implementation
- Any other matters relating to energy

Energy Manager

A full-time energy manager may be appointed to implement the energy management programme, directly accountable to the energy committee. This would also be evidence of the management concern for and commitment to energy conservation. The energy manager should be an internal appointee, to ensure good practical knowledge of all aspects of operations, both technical and administrative.

Responsibility for Results

Appendix 5 : Energy Audit Approach and Methodology

In general, organisation structures in the industry are based on three levels of authority with corresponding responsibilities towards efficiency of energy use.

Level 1: Senior Management with responsibility for energy efficiency in the entire organisation, in relation to other resources, and in production of particular products.

Level 2: Middle Management with similar responsibilities, but limited to specific areas of the manufacturing process or divisions of the organisation.

Level 3: Process Operators, Foremen and Supervisors with responsibility for maintaining efficiency in a particular item of plant or part of a process.

At all levels, regular reports on actual usage compared against norms and targets will be required in order to learn and correct deviations. The energy manager would provide these reports, analyse data, develop standards of performance and derive information for setting appropriate targets. He would also be responsible for installation and operation of metering systems and the training of staff for the collection and analysis of data.

Energy Management Process/Strategy

There are four distinct steps to the energy management process:

- Defining energy accounting centres
- Measurement
- Analysis & Monitoring
- Targeting

Energy Accounting Centres (EAC)

Along the energy flow paths of the plant, a series of energy accounting centres can provide the breakdown of energy input and output, for monitoring and achieving set targets. An EAC might comprise an individual equipment, a section or even a whole building. Each centre must have an individual responsible for both operational achievement and energy conservation, in order that his attention is focussed on the close relationship between the two aspects. He should have available pertinent information, on which to base judgements, decisions and actions to bring about improvements. Each EAC requires meters to measure the energy consumed over a period, and a means of measuring the production (or other specific variable) over the same period. As far as possible, EACs should correspond with existing cost control centres.

Measurement

In order to be managed effectively, any resource must be measured accurately, to provide information to base decisions. Energy management depends on collection of relevant data, to judge current performance and plan for future improvements.

Analysis & Monitoring

Energy consumption and cost data can be collected and effectively used to analyse and evaluate performance. This involves regularly comparison of actual levels of consumption with a theoretical consumption defined by a set of internally based standards. These standards could be derived from a knowledge of the organisation's own capability, and then possibly further checked by reference to external norms. Difference between actual consumption and the corresponding standards will reveal either improvements in energy efficiency or a fall-off in performance levels. The information gathered, thus provides quantified evidence of the success of implementation, or will indicate any failures, in order that remedial measures can be undertaken.

The analysis should be a continuous process, and each line manager or plant operator must receive the energy throughput data regularly - on a weekly/ monthly basis - and promptly, so that deviations from standards can be quickly detected and corrected. In turn, line managers themselves must ensure that they respond rapidly to the information they receive. Well-designed reporting forms, expressed in readily understood terms, will be very helpful. Management information systems must ensure that the appropriate data and deviations reach the highest levels of authority. Just by the introduction of a monitoring system alone, many organisations have found that they could cut their energy consumption by up to ten percent.

Targeting

Once the energy management programme has identified and prioritised on the implementation of various measures, targets can be set for the implementation of change and the achievement of the predicted energy cost savings. The choice of targets will take account of current standards and the time frame for implementing measures. A organisation may wish to set a range of targets, taking note of the scope for improvement, the resources allowed by management to effect the improvement and the need to match accountability to the energy-accountable centres.

There are two principal methods of target setting. This first is the `top down' approach, a broad based generalised technique, which does not draw on a detailed analysis of the circumstances of the organisation, but may be based on experience in the sector as a whole.

The second `bottom up' method is based on a close knowledge of the energy requirements of different parts of an organisation. Both have their merits and can be chosen, depending on the efficacy in the given circumstances. Most organisations prefer the `bottom up' approach since it is, by its very nature, more closely tailored to there needs and hence more effective.

Correctly set targets have a strong motivational effect on the workforce. But it is important to avoid either impossible or too easy targets, since these can provide counter productive.

Importance of Human Element

Good Co-operation from Personnel

a. Education

A well-designed familiarisation programme should convince employees of the need for good standards of housekeeping and energy awareness. They should appreciate that it is in their best interests to avoid unnecessary and excessive use of energy. Energy savings add directly to profit. However, it is important to emphasise that sacrifices are not being sought, nor are the employees expected to work in less than satisfactory conditions.

Early results are unlikely to be sustained indefinitely. People do tend to slip back into former habits, but the right climate can be established for introducing more complex and lasting measures gradually.

b. Awareness and information sharing

In most plants, employees have little or no idea of the amount of energy consumed within their plant, their section and even the equipment operated by them. In such a situation, what is required is awareness - which can be possible only by information, in the form of comparisons of historical trends, goals for overall energy use, energy intensity, in physical and monetary terms; checklists for each manufacturing operation outlining routine housekeeping measures, audio-visual presentations and literature.

Information must be presented in a manner which facilitates comprehension. If the information is too technical, theoretical, sketchy or dull, it is likely to be ignored or not understood. Terminology should be familiar to the daily life of the employees. For example, a sign saying, " stop steam leaks" will not be as effective as a sign saying " A quarter inch diameter steam leak costs Rs. 30,000/- per month".

Training is also an important means of both informing and involving people at all levels in an energy management programme. For operating personnel, training is required in practicalities of energy saving. This could be integrated into the organisation's other training programmes.

c. Motivation

Motivation is based on involvement, commitment and a sense of personal accountability. Top management must visibly demonstrate their attitude, originate the programme, generate and maintain the momentum.

Operators and maintenance staff should be involved actively, as they are ultimately responsible for execution. They are often in a better position to recommend areas for improvement. The most effective way of involving them is by simply going out and talking to them regarding goals, achievements, problems and progress or lack of progress.

Supervisors and middle level management should be involved by being assigned responsibilities for implementing and monitoring activities and submitting performance reports to top management, and by getting them to interact and communicate with operators and maintenance stand on progress and problems. If possible, energy management activities should be made a part of each supervisor's performance or job standard.

d. Publicity

Publicity and promotion are essential to publicise the benefits to the company and the workforce. Some commonly used means could be:

1. *Articles or implemented ideas in company or plant paper.*
2. *Obtain local newspaper interest and coverage.*
3. *Posters and pamphlets*
4. *Letterheads with energy conservation messages and ideas*
5. *Plant-wide, high-visibility vehicles or equipment to carry signboards*
6. *Monthly posting of results for the plant and department*
7. *Direct interactions of plant energy manager and personnel.*
8. *Quarterly site reviews and walk-through of unit.*
9. *An agenda item on energy conservation included at staff meetings.*
10. *Material provided to first-line supervisors for employee discussion periods.*
11. *Quarterly meetings held in the plant for all unit representatives*
12. *An Energy Awareness Day is set aside in the plant twice a year*
13. *A Company energy logo developed and adopted.*

Key Tasks of Energy Management

Energy Data Collection and Analysis

➢

➢ Maintain records of all energy consumption in the plant

➢ Check the reading of all meters and sub-meters on a regular basis.

➢ Specify additional meters required to provide additional monitoring capability.

➢ Develop indices for specific energy consumption relative to production and maintain these indices on a monthly basis for all major production areas.

➢ Set performance standards for efficient operation of machinery and facilities.

Energy Purchasing Supervision

-
- Review utility and fuel bills; ensure proper and optimum tariff application
- Investigate and recommend fuel-switching opportunities
- Develop contingency plans in the event of supply interruptions or shortages.
- Work with individual departments to prepare annual energy cost budgets.

Energy Conservation Project Evaluation

- Develop ideas, working with in-house staff, vendors and consultants.
- Analyse economics to permit management evaluation of projects.
- Obtain management commitment of funds to implement projects.
- Re-evaluate projects in tune with growth of company

Energy Project Implementation

- Initiate equipment maintenance programmes for energy saving
- Supervise the implementation of conservation projects, including specification, requests for quotation, evaluation of offers, ordering of materials, construction/installation, training, start-up and final acceptance.

Communications and Public Relations

- Prepare reports to management, summarising costs and consumption
- Effectively communicate with all production and support departments
- Develop an awareness programme to encourage active participation
- Develop training programmes to upgrade knowledge and skills
- Publicise company commitment to energy conservation

Checklist for Top Management

a. Inform line supervisors of:

- Economic reasons to conserve energy.
- Responsibility for implementing actions in areas of accountability.

b. Establish an energy committee consisting of:

- Representatives from each department in the plant
- A co-ordinator appointed by and reporting to management.

c. Provide committee with guidelines as to what is expected of it:

- Develop uniform record keeping, reporting and energy accounting.
- Research and develop ideas on ways to save energy.
- Communicate these ideas and suggestions.
- Suggest tough, but achievable, goals for energy saving.
- Develop ideas for enlisting employee support and participation.

d. Set goals in energy saving, revising it based on savings potential

e. Employ external assistance in making recommendations.

f. Emphasise management's focus on conservation activities.

Appendix 5 : Energy Audit Approach and Methodology

Duties and Responsibilities of Energy Manager/Co-Ordinator

- Generate interest in conservation and sustain it with new ideas and activities.
- Summarise purchases, stocks and consumption, review and report utilisation.
- Focus of departmental records of use, ensuring uniformity and consistency.
- Co-ordinate efforts of energy users and set challenging but realistic targets
- Advise on techniques and source guidance on specialised subjects.
- Identify areas that require detailed study and prioritise them.
- Maintain records of all in-depth studies and to review progress.
- Provide basic handbook of good energy practice for operations.
- Advise purchasing, planning, production and other functions
- Ensure that health and safety are not adversely affected.
- Liase within industry to exchange ideas, protecting confidential data
- Contact research organisations, manufacturers and professional bodies
- Remain up-to-date on national energy matters and advise senior management.

Instrumentation for Energy Audit

Thermal related measurements:

The most common parameter measured is temperature. All evaluations of the heat contents of a stream or the energy consumption of a process depend on the temperature at each point of the stream or in the process. The instruments commonly used for measuring temperature are:

- Mercury/ Bimetallic thermometer
- Thermocouple and indicator
- Thermograph
- Data logger
- Pyrometer
- Hygrometer

Mechanical related measurements:

Flow measuring instruments:

- Vane anemometer
- Pitot tube
- Air flow meter
- Orifice meter
- Venturi meter
- Ultrasonic flow meter

Pressure measuring instruments:

- Bourdon gauge
- Manometer (U-Tube and Micro)
- Pressure recorders

Ultrasonic Leak Detectors

Speed measuring instruments:

- Tachometers (Contact and Non-Contact Type)
- Stroboscope

Steam trap-testing instruments:

- Industrial stethoscope
- Electronic trap tester

Chemical related measurements

- Fyrite kit (percentage CO_2/ O_2 in the flue gas)
- Oxyliser (% O_2, CO_2, flue gas temperature and combustion efficiency)
- Flue gas analyser (%O_2,CO_2,flue gas temperature and combustion efficiency)
- Dragger (CO)

Electrical related measurements:

- Ammeter and Voltmeter
- Power factor meter
- Power analyser (A,V, pf, kW, kVA, Hz)
- Current recorder
- Multi-meter

Lighting related measurements:

- Lux meter

- Mini S
- Steel
- Brewe
- Glass
- Textile
- Steel F
- Distille

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- Steam (
and Utilisation
- Compressed Air Systems
- Pumping Systems
- Industrial Electricity Supply Sys
- Dryers and Evaporators
- Electric Motors (Under Prepara
- Oil Fired Furnaces (Under Preparation)

- ~~Electric Furnaces~~
(Under Preparation)
- Refrigeration & Air-Conditioning
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- Lighting Illumination
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- wers (Under Preparation)
- DG Sets (Under Preparation)